April 2011

Environmental Technology Verification Report

EnviroScan, Inc. Ozone Detector Card

Prepared by

Battelle

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EPA **U.S. Environmental Protection Agency**

ETV ETV ETV

Environmental Technology Verification Report

ETV Advanced Monitoring Systems Center

ENVIROSCAN, INC. OZONE DETECTOR CARD

by

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Notice

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Foreword

The EPA is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. ETV consists of six environmental technology centers. Information about each of these centers can be found on the Internet at http://www.epa.gov/etv/.

Effective verifications of monitoring technologies are needed to assess environmental quality and to supply cost and performance data to select the most appropriate technology for that assessment. Under a cooperative agreement, Battelle has received EPA funding to plan, coordinate, and conduct such verification tests for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/nrmrl/std/etv/verifiedtechnologies.html#air.

Acknowledgments

The authors wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. Quality assurance (QA) oversight was provided by Michelle Henderson, U.S. EPA and Rosanna Buhl and Zachary Willenberg, Battelle. We thank Rudy Eden, Philip Fine, Jason Low, and their staff of the South Coast Air Quality Management District for their contributions in field testing of the Ozone Detector Cards. We also thank Daniel Witzling and Neal Richman of Breathe California of Los Angeles for their financial support of this test, and their volunteers for using the Ozone Detector Cards in the field. We also thank Mr. Eden, Mr. Richman, Mr. David Shelow (U.S. EPA), and Dr. Will Ollison (American Petroleum Institute) for their reviews of this verification report.

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AMS	Advanced Monitoring Systems
ADQ	audit of data quality
BCLA	Breathe California of Los Angeles
cm	centimeter(s)
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
FEM	Federal Equivalent Method
FRM	Federal Reference Method
ft	foot (feet)
in	inch(es)
L	Liter(s)
m	meter(s)
min	minute(s)
mph	miles per hour
nm	nanometer
OEPA	Ohio Environmental Protection Agency
PE	performance evaluation
ppbv	parts per billion by volume
QA	quality assurance
QC	quality control
QMP	quality management plan
RH	relative humidity
sec	second(s)
SCAQMD	South Coast Air Quality Management District
TSA	technical systems audit
UV	ultraviolet
$\mu W/cm^2$	microwatts per square centimeter

Chapter 1
Background

The U.S. Environmental Protection Agency (EPA) supports the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance and quality control (QA/QC) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Risk Management Research Laboratory and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center recently evaluated the performance of EnviroScan, Inc.'s Ozone Detector Cards in laboratory tests conducted at Battelle's laboratories in Columbus, OH and field tests conducted in southern California. Ozone indicator cards were identified as a priority technology category for verification through the AMS Center stakeholder process.

Chapter 2
Technology Description

This report provides results for the verification testing of EnviroScan, Inc.'s Ozone Detector Card. The following is a description of the Ozone Detector Card, based on information provided by the vendor. The information provided below was not verified in this test.

The Ozone Detector Card (Figure 2-1) is approximately 8 centimeters (cm) x 11 cm (3.25 inches (in) x 4.25 in) in size. Each card has a row of five spots of solid reagent, with each spot covered by a protective strip of foil. When a foil strip is removed and the reagent spot is exposed to air, the reagent reacts with ozone in the air to produce a color change in the spot proportional to the ozone concentration. An ozone measurement is conducted by removing the foil from a spot and placing the card in the atmosphere to be tested for 10 minutes (min). At the end of the 10 min measurement, the card is folded onto itself and the color of the reacted spot is compared visually through a hole in the card to a reference color wheel printed on the front of the Ozone Detector Card. The color wheel has four gradations corresponding to four different ranges of ozone concentrations. The vendor describes those four ranges as follows:

- Range 1 (10 to 45 parts per billion by volume (ppbv) ozone) corresponds to conditions with no or very little ozone pollution.
- Range 2 (45 to 75 ppbv ozone) corresponds to normal ozone pollution on sunny days.
- Range 3 (75 to 105 ppbv ozone) corresponds to potentially unhealthy conditions in which children, asthmatics, and people with other respiratory diseases should limit prolonged outdoor exertion.
- Range 4 (>105 ppbv ozone) corresponds to unhealthy conditions in which children, asthmatics, and people with other respiratory diseases should avoid outdoor exertion and everyone else should limit outdoor exertion.

With a 10-minute exposure period, the degree of reagent color change increases progressively from little to no change for Range 1 to significant darkening of the reagent spot for Range 4.

For ambient ozone measurements, the Ozone Detector Card should be placed outdoors in a location where it is protected from the wind. Measurements conducted in windy conditions may produce incorrect results. Additionally, the Ozone Detector Card can be used to measure indoor ozone concentrations with a recommended exposure time of 20 min (as opposed to 10 min for outdoor measurements). The longer indoor exposure time is intended to produce a measurable reagent color change with the relatively lower ozone concentrations expected indoors. (Note added by Battelle: the instructions for use of the Ozone Detector Card do not include any adjustment to the visual readings to account for the longer exposure time when used indoors.)

Figure 2-1. EnviroScan Ozone Detector Card folded (top) and open (bottom).

Chapter 3
Test Design and Procedures

3.1 Introduction

Ozone is a widespread pollutant that is formed by photochemical reactions involving sunlight, nitrogen oxides, and volatile organic compounds in air. The U.S. Clean Air Act and its Amendments led to the establishment of air quality standards for ozone, and pollution control strategies that require state and local authorities to regulate for compliance with the standards. Ozone is regulated because of its effect on human health when air containing elevated concentrations of ozone is inhaled.

Because of the costs associated with emission control programs and penalties for those regions that are not in compliance, it is essential that ozone measurements that determine compliance with standards be accurate. For that purpose EPA has established Federal Reference and Equivalent Methods (FRM and FEM) for monitoring ozone.[1] The method currently widely used is the FEM, which makes use of the ozone molecule's strong absorption band in the ultraviolet (UV) region of the spectrum, with a maximum coinciding with the strong mercury vapor emission line at 254 nanometers (nm). The FEM has completely supplanted the FRM for all compliance monitoring in the U.S., because of the greater complexity of the FRM and its requirement for flammable ethylene gas. Commercial FEM instruments measure the transmission of UV light through an air sample and compare the intensity with that obtained along the same path length through air containing no ozone. A scrubber (typically MnO_2 or heated silver wool) designed to selectively remove ozone from the air, is used to allow determination of the background absorption of UV light by non-ozone species such as aromatic organic compounds. Potential interferences in the FEM ozone measurement, due to removal of UV-absorbing aromatic compounds by the ozone scrubber, have been identified and may be significant in polluted conditions that can produce elevated ozone levels exceeding regulatory standards.[2]

For rapid assessment of human exposure to ozone, methods less expensive and complex than a FRM or FEM can be useful. Semi-quantitative methods that indicate a range of ozone concentrations in air can be helpful to people with ailments that cause respiratory sensitivity to ozone. One simple and inexpensive approach to personal ozone measurement is the use of a colorimetric indicator card which incorporates a reagent that undergoes a color change when exposed to ozone in air. To use the card, a protective foil over a reagent spot is removed and the spot is exposed to ambient air for a specified period of time (e.g., 10 min). Then the intensity of the resulting color change in the reagent spot is visually compared to a color reference printed on the card, providing an estimate of the ozone concentration range. Such indicator cards typically indicate ozone concentrations in a few broad concentration ranges from near zero to over 100 ppbv. The EnviroScan, Inc. Ozone Detector Card is an example of this class of indicator cards. This verification evaluates the ease of use of the Ozone Detector Cards and quantifies their response relative to the response of FEM instrumentation so potential users can make informed decisions about the potential benefits and limitations of the cards.

This verification test was conducted over a 12-month period beginning in October 2009 and ending in October 2010, according to procedures specified in the *Test/QA Plan for Verification of Ozone Indicator Cards*.[3] As indicated in the test/QA plan, the testing conducted satisfied EPA QA Category III requirements. The test/QA plan and/or this verification report were reviewed by:

- Rudy Eden, California South Coast Air Quality Management District (SCAQMD)
- Will Ollison, American Petroleum Institute
- David Shelow, U.S. EPA
- Daniel Witzling (test/QA plan only) and Neal Richman (report only), Breathe California of Los Angeles (BCLA).

3.2 Test Procedures

The verification of the EnviroScan Ozone Detector Card included both laboratory and field testing. Laboratory testing was conducted in Battelle's facilities in Columbus, Ohio. Field testing was conducted at monitoring sites in the Los Angeles Basin of Southern California by staff of the SCAQMD. Additional data were obtained in the field by volunteers coordinated by BCLA. These testing efforts are described below.

3.2.1 Laboratory Testing

The laboratory portion of the test was conducted over a period of approximately 30 days and involved delivering known concentrations of ozone in a continuously flowing air stream at room temperature to an 8 L test chamber. The delivered ozone concentrations were monitored simultaneously by both an FEM and Ozone Detector Cards. The FEM used was a Thermo Environmental Model 49C Ozone Monitor (FEM EQOA-0880-047) with an upper range limit of 200 ppbv. Prior to the start of testing, the Model 49C Ozone Monitor was calibrated against a Dasibi Model 1008 UV calibration photometer which had itself been calibrated against the Ohio Environmental Protection Agency's (OEPA) ozone calibration standard photometer.

At the start of every day of testing, a zero and span check of the Model 49C Ozone Monitor were conducted using the Dasibi reference photometer. During testing of the Ozone Detector Cards, the Dasibi was removed and a humidification system was connected to the test apparatus. Humidified air from this system was mixed upstream of the test chamber with the dry ozonated air flow from an Environics Model 6100 ozone generator to provide approximately 20 L/min total air flow with a relative humidity (RH) of 50 (±5) % for all tests. The resulting speed of air movement through the 8 L test chamber was approximately 1 cm/sec (0.6 meter (m)/min (2 feet (ft)/min)). Ozone Detector Cards were inserted into the test chamber and exposed to the delivered ozone concentrations for 10-min periods. FEM ozone data were logged continuously before, during, and after each Ozone Detector Card exposure. The temperature and relative humidity in the chamber were also monitored and logged continuously during each test. Figure 3-1 shows the test setup including the chamber, Environics ozone generator, FEM, Dasibi photometer, data logger (Fluke, Hydra Series II), humidity generator (Fuel Cell Technologies, Model LF-HBA), and temperature/humidity probe (Onset, HOBO Model H14-002/S-THA-M002).

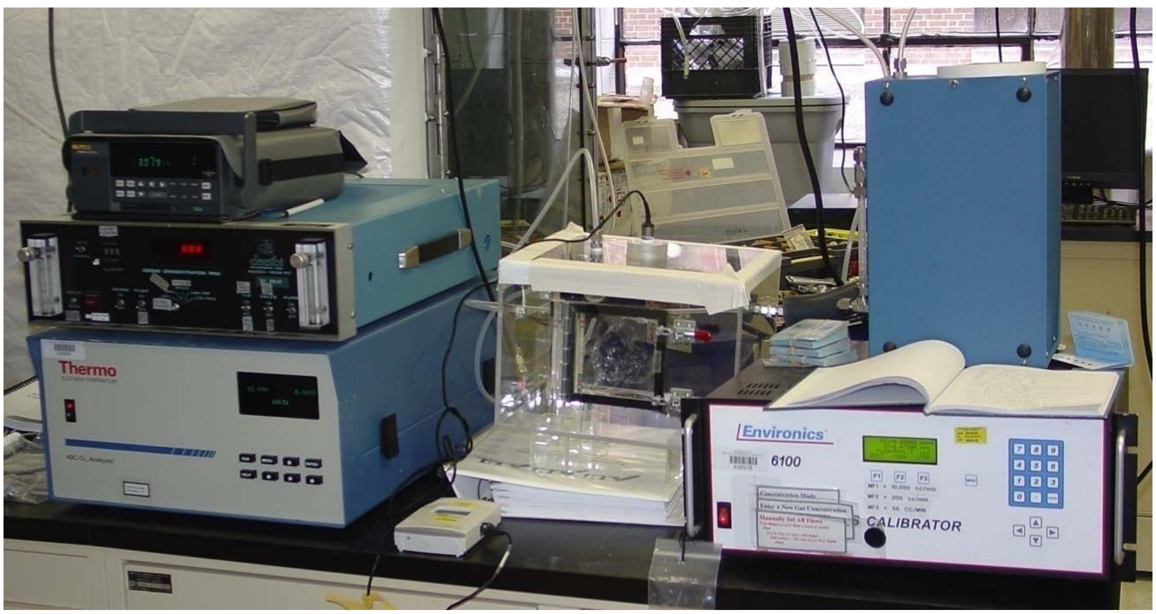

Figure 3-1. Laboratory Test Setup

Following each exposure to the delivered ozone concentrations, the exposed Ozone Detector Cards were removed from the test chamber and taken within 30 sec to two separate Battelle administrative staff members who independently recorded their visual readings of the color of the exposed reagent spot(s) (i.e., readings from 1 to 4 based on the reference color wheel printed on the card). Those staff members (the card readers) did not know the ozone concentration delivered to the cards, which was known only by the Battelle employee conducting the test. Each reader's observations were collected and entered into an electronic spreadsheet at the end of each testing day. The two administrative staff members providing the visual readings were non-technical personnel who were trained in use of the cards before testing began. These staff members did not confer with each other about their observations at any time during testing.

During the laboratory testing, two reagent spots on each of four Ozone Detector Cards were exposed simultaneously during each test (for a total of eight spots exposed simultaneously per test). In half of the tests, the foil was also removed from one additional reagent spot on each card after the cards were removed from the test chamber, and within 30 sec before the cards were given to the two card readers. These additional spots were used as blanks to determine if the readers perceived a color change on a spot that had not been exposed to ozone. Readers were asked to record observations of the color of all reagent spots that had been uncovered.

While conducting the initial laboratory tests, it was observed by the staff conducting the test that insertion of the Ozone Detector Cards into the test chamber resulted in a decrease in the ozone concentration in the chamber, as measured by the FEM ozone monitor. The percentage decrease in ozone due to the presence of the four Ozone Detector Cards was approximately 20%, and was the same when all reagent spots were covered with foil as when all reagent spots were uncovered. That decrease was not transitory, but persisted as long as the Ozone Detector Cards remained in the test chamber. To counteract this effect, the initial ozone concentration in the chamber was set approximately 20% higher than the target test concentration so that the target concentration was achieved once the Ozone Detector Cards were in place.

A test matrix with six ozone concentrations (0, 30, 50, 70, 90, and 130 ppbv) was used for this evaluation. These values were chosen to include both concentrations near the midpoint of card ranges (i.e., 30 and 90 ppbv) and concentrations near the boundaries of a range (i.e., 50 and 70 ppbv). Testing at each concentration was conducted twice for a total of 12 separate ozone exposure tests, with the six concentrations delivered in random order. At the start of each test the ozone concentration in the chamber was determined by the FEM prior to the insertion of the Ozone Detector Cards. FEM ozone monitoring then continued as the foil covering was removed from two spots on each of four cards and the cards were placed in the chamber for a 10 min exposure. Each Ozone Detector Card was numbered uniquely and the spots on each card were numbered from 1 to 5. The card/spot numbers for each test were recorded at the start of every test. The ozone concentration during the 10 min exposure was recorded in a laboratory notebook as well as being recorded continuously by the data logging system. At the end of the 10 min exposure, the Ozone Detector Cards were removed from the chamber and the foil was removed from any scheduled blank spots. Within 30 sec after the end of the ozone exposure period, the cards were then taken to the two Battelle card readers to be read. Each card reader visually inspected each card at their desk under overhead fluorescent lighting in a windowless office, and recorded the card and spot numbers and their observations of the ozone range readings for each exposed spot.

During laboratory testing, the staff conducting the test observed that even with delivered ozone concentrations exceeding 120 ppbv, neither Battelle card reader ever classified the Ozone Detector Card color change as Range 4. Consequently, to determine the ozone concentrations at which users would classify the color change as Range 4, additional tests were performed at higher concentrations (up to and exceeding the 200 ppbv range limit of the FEM).

Tests were also conducted to evaluate the effect of light intensity during ozone exposure on reagent color development in the Ozone Detector Cards. In this testing, two reagent spots on four Ozone Detector Cards were exposed simultaneously to approximately 100 ppbv of ozone in air at 22 °C and 50% RH, with the test conducted under normal indoor laboratory illumination. The same test was then repeated with the Ozone Detector Cards in darkness during O_3 exposure, and was then repeated once more with the Ozone Detector Cards illuminated by sunlamps and a UV lamp to achieve a light intensity simulating illumination outdoors by a full overhead sun. These test conditions were designated as the Laboratory, Dark, and Bright conditions. After each ozone exposure the Ozone Indicator Cards were removed from the test chamber and taken within 30 sec to the two Battelle card readers for visual reading under overhead fluorescent lighting in windowless offices. The Ozone Detector Card results from the three trials (i.e., eight readings by each of two readers at each of three light intensities) were compared to assess whether the light intensity during ozone exposure affects the Ozone Detector Card readings.

For each light intensity test the total light intensity at the card surfaces was measured using a DLM 2000 lux meter (Mannix, New York, NY) (1 lux = 1 lumen/m^2 (≈ 0.1 footcandle)). For the Bright light test, the solar intensity and spectrum were simulated using the combination of two full daylight spectrum fluorescent flood lamps (GE BE 26 PAR38/D) and a mercury vapor UV flood lamp (PowerSun UV 100W, Zoo Med Laboratories, Inc., San Luis Obispo, CA). These lamps were positioned at the test chamber to directly illuminate the exposed surfaces of the Ozone Indicator Cards during the ozone exposure. In the Bright light test the intensities at the card surfaces of UV-A (280-400 nm wavelength), UV-B (280-320 nm), and UV-C (< 280 nm) were also measured using Solarmeter® Digital Ultraviolet Radiometers, Model 5.7 (UV-A+B), Model 6.2 (UV-B), and Model 8.0 (UV-C) (Solartech, Inc., Harrison Twp, MI). The measured total light intensities at the card surfaces in the Laboratory, Dark, and Bright light conditions were 175, 3.5, and over 40,000 lux, respectively. The UV intensities during the Bright light test were 146, 84, and zero microwatts per square centimeter µW/cm^2 for UV-A, UV-B, and UV-C, respectively.

3.2.2 Field Testing

Testing conducted in the field by SCAQMD personnel consisted of exposing one or more spots on one or more Ozone Detector Cards simultaneously, at ambient ozone monitoring sites where an FEM monitor is deployed for continuous compliance monitoring. SCAQMD personnel used pre-printed data collection forms to record the date, site location, user initials, Ozone Detector Card identification number(s), reagent spot number(s), start and end times of exposure, initial and final visual readings of the spots, and the ambient temperature, RH, wind speed, and FEM ozone reading during each exposure period. The SCAQMD ozone monitoring sites used in the field testing were those in Crestline, Riverside, Rubidoux, Santa Clarita, and Upland, California. The elevations of these sites range from approximately 250 m (800 ft) above sea level at Rubidoux and Riverside to 1,400 m (4,600 ft) above sea level at Crestline. These elevation differences result in an average difference in atmospheric pressure of approximately 100 millimeters of mercury between the highest and lowest sites. Consequently, the absolute concentration of ozone molecules in air at a constant ambient ppbv concentration (i.e., mixing ratio) is approximately 13% lower at the Crestline site than at the lowest sites. This difference in absolute ozone concentration at the same ppbv concentration was considered in evaluating the accuracy of the Ozone Detector Cards in the SCAQMD testing.

At each SCAQMD site the Ozone Detector Cards were exposed to ambient air at a height of approximately 3 to 6 ft above the ground, whereas the sample inlets of the FEM ozone monitors were approximately 12 to 15 ft above the ground. Over those vertical distances, ozone at the SCAQMD sites is not expected to exhibit vertical gradients significant enough to affect the comparison of FEM and Ozone Detector Card readings. A total of 462 reagent spots on 99 Ozone Detector Cards were exposed and read by SCAQMD personnel for comparison to FEM readings in the field.

Additional testing by BCLA consisted of having volunteers expose and subsequently visually read reagent spots on Ozone Detector Cards in indoor and outdoor locations at schools, playgrounds, and parks. BCLA volunteers used pre-printed data collection forms to record the date, location, user initials, Ozone Detector Card identification number(s), reagent spot number(s), times of exposure, and the visual readings of the spots. A total of 64 reagent spots on 14 cards were exposed by BCLA volunteers for recording of readings in the field.

3.3 Performance Parameters Tested

3.3.1 Accuracy

The accuracy of the Ozone Detector Cards was determined by comparing Ozone Detector Card readings determined visually to simultaneous measurements made using the FEM both in the laboratory and in the field.

3.3.2 Variability of Readings

Variability of Ozone Detector Card readings refers to the consistency, or lack thereof, in visually determined Ozone Detector Card results with a constant ozone concentration. Variability was assessed using the multiple readings made by each of two users at six ozone concentrations in the laboratory testing described in Section 3.2.1.

3.3.3 Duplication

The degree of agreement of ozone measurements made simultaneously on different Ozone Detector Cards or different reagent spots was assessed using all data in which simultaneously exposed reagent spots were read by a single user. Similarly, the degree of agreement of ozone measurements made by separate users was assessed using all data in which the same exposed Ozone Detector Card reagent spot was read by more than one user. These two measures of performance are termed Ozone Detector Card duplication and user agreement, respectively, and are intended to address two types of variation in Ozone Detector Card readings. Ozone Detector Card duplication addresses within-user variation (and consists of both inter-card duplication and intra-card duplication), whereas user duplication addresses between-user variation. Within-user variation arises from differences in the color development of different reagent spots that have been exposed under identical conditions. Between-user variation arises from visual perception differences in readings made by different individual users on identically the same exposed reagent spot. These two forms of duplication were evaluated by means of the unique numbering of Ozone Detector Cards and reagent spots, and by separate recording of readings made by different users.

Data to assess both Ozone Detector Card duplication and user agreement were generated from the laboratory testing. Relevant data also originated in the field testing, whenever either SCAQMD or BCLA representatives reported visual readings for simultaneously exposed reagent spots, or visual readings from two different users for the same reagent spot. Such duplicate readings were recorded on the field data sheets used by SCAQMD and BCLA representatives. In all cases duplicate readings (whether of duplicate Ozone Detector Card reagent spots by a single user or of a single Ozone Detector Card reagent spots by multiple users) were taken in close succession and under identical lighting conditions immediately after the Ozone Detector Card exposure period.

3.3.4 Effect of Light Intensity

The effect of light intensity on reagent spot color development was assessed based on the readings made at a constant ozone concentration under three different light intensity conditions.

3.3.5 Effect of Ambient Conditions

The effect of ambient temperature, RH, and wind speed was evaluated based on information provided by SCAQMD personnel from the field sites. The Ozone Detector Card and FEM field ozone results used to determine Ozone Detector Card accuracy were segregated into those showing agreement between Ozone Detector Card and FEM results and those showing disagreement. Then the temperature, RH, and wind speed conditions associated with these two data sets were compared.

3.3.6 Operational Factors

Operational factors associated with use of the Ozone Detector Cards were evaluated based on the comments and observations of all users (Battelle, SCAQMD, and BCLA) in the laboratory and field testing. Such observations addressed the convenience of the Ozone Detector Cards, their readability under differing conditions, the apparent consistency of Ozone Detector Card readings, and other factors. Cost was evaluated based on published price lists obtained from the vendor.

3.4 Verification Schedule

The Ozone Detector Card laboratory testing was conducted at Battelle's laboratories in Columbus, Ohio between January 20, 2010 and February 25, 2010. Initial field testing with the Ozone Detector Cards was conducted by SCAQMD between October 1 and November 2, 2009. Although conducted in accordance with the test/QA plan,[3] this initial testing took place before final approval of the test/QA plan. Consequently, data and results from that portion of testing are included only as auxiliary data in Appendix A of this report. Field testing was conducted by BCLA volunteers between December 18, 2009 and May 13, 2010. Those initial SCAQMD and BCLA field tests used Ozone Detector Cards from the same batch of cards used for the laboratory testing. The vendor states that the shelf life of the Ozone Detector Cards is one year, however a new batch of cards was obtained in June 2010 for use when field testing resumed during the late summer and fall of 2010. With the new batch of cards, SCAQMD conducted field testing between August 24 and October 5, 2010.

Chapter 4
Quality Assurance/Quality Control

QA/QC procedures and all verification testing were performed in accordance with test/QA plan for this verification test[3] and the quality management plan (QMP) for the AMS Center.[4] QA/QC procedures and results are described below.

4.1 Reference Methods

The following sections describe the QA/QC procedures employed in the collection and analysis of reference samples.

The quality of the laboratory reference ozone measurements was assured by a calibration of the FEM ozone analyzer before any testing, and a daily zero and span check of the FEM analyzer at the start of each day of testing, using the Dasibi 1008 UV ozone transfer standard. The pre-testing calibration data are presented in Table 4-1. The slope of the linear regression of Thermo 49C FEM readings against the transfer standard Dasibi 1008 UV readings was 0.96, the intercept was -0.2 ppbv, and the coefficient of determination (r^2) was 0.9999. This calibration was used to correct all laboratory FEM data to the Dasibi 1008 UV readings. It should be noted that some of the highest ozone concentrations used in laboratory testing (see Section 3.2.1) exceeded the 150 ppbv upper end of the FEM calibration. Those data points were used to assess the ability of the Ozone Detector Cards to exhibit a range reading of 4. The validity of FEM readings at those concentrations is supported by the demonstrated linearity of the FEM response on its 200 ppbv range.

The FEM reading on the one-point daily span check was within 5% of the ozone concentration from the Dasibi 1008 UV on every day of testing. Quality of the field reference ozone measurements was assured by QA review of the SCAQMD records of the calibration and maintenance of FEM monitors used for ozone compliance monitoring at the field sites.

Table 4-1. Results of Pre-Test Ozone FEM Calibration

Nominal Concentration Delivered by Environics 6100 (ppbv)	Measured Dasibi 1008 UV Photometer Concentration (ppbv)	Measured Thermo 49C Ozone Monitor Concentration (ppbv)
0	1.8	1.6
30	35	32
60	65	62
90	98	93
120	127	122
150	159	152

4.2 Audits

Three types of audits were performed during the verification test: a performance evaluation (PE) audit of the Dasibi 1008 UV photometer transfer standard, a technical systems audit (TSA) of the verification test procedures, and an audit of data quality (ADQ). Each audit was documented in accordance with Sections 3.3.4 and 3.3.5 of the QMP for the ETV AMS Center.[4] Audit procedures are described further below.

4.2.1 Performance Evaluation Audit

A PE audit of the ozone measurements was performed to confirm the accuracy of the Battelle-owned Dasibi 1008 UV photometer as the basis for the FEM calibration in this verification. A side-by-side comparison was conducted to establish the traceability of the Battelle Dasibi 1008 UV photometer relative to the ozone standard owned by the OEPA, which is a Thermo Environmental Model 49, Serial Number 72903-372, and which is traceable to the primary ozone standard reference photometer located at EPA Region 5, Chicago, Illinois. In the side-by-side comparison, the slope of the regression of Battelle Dasibi 1008 UV readings against OEPA readings was 0.99, the intercept was 1.3 ppbv, and the coefficient of determination (r^2) was greater than 0.9999. All of these measures fell within the OEPA requirements for verification (slope of 1.00 ± 0.05 and intercept < 5 ppbv).

4.2.2 Technical Systems Audit

The Battelle Quality Manager performed a TSA of the laboratory testing procedures during the first week of the laboratory testing. The purpose of the laboratory TSA was to ensure that the verification test was being performed in accordance with the AMS Center QMP,[4] the test/QA plan for this verification test,[3] and the reference methods. In this TSA, the Battelle Quality Manager reviewed the reference method used, compared the actual test procedures being performed to those specified or referenced in the test/QA plan, and reviewed data acquisition and handling procedures. During the laboratory TSA, the Battelle Quality Manager observed the reference method sampling; inspected documentation of test procedures; and reviewed laboratory record books. Six deviations from the test/QA plan were noted in this TSA. Some were the result of deliberate choices to improve the test procedures; the others were readily addressed and had no significant effect on data quality. The six deviations were:

- Extension of the lower limit of calibration of the FEM from 10 ppbv to zero ppbv.
- Use of additional challenge ozone concentrations above the 150 ppbv upper limit of the FEM calibration range (noted in Section 4.1).
- Use of the Dasibi 1008 UV readings, rather than the Environics 6100 ozone source output, as the transfer standard for comparison to FEM readings in daily calibration checks.
- Use of a 100 ppbv concentration of ozone in the light intensity testing, instead of 60 ppbv as stated in the test/QA plan, to assure production of a color change with the Ozone Detector Cards and increase the likelihood of detecting a light intensity effect.
- Exposure of eight spots (two spots on each of four cards) rather than 10 (five spots on each of two cards) in the light intensity testing, to provide greater consistency with other test procedures.
- Occasional departures from recording procedures in the laboratory notebook (e.g., absence of units on ozone concentrations; corrections not properly initialed and dated).

A formal description and response to these deviations was prepared, signed by Battelle's Verification Test Coordinator, AMS Center Manager, and AMS Center Quality Manager, provided to the EPA AMS Center Project Officer and Quality Manager, and retained in the study files. A second such deviation form was similarly prepared, approved and distributed, documenting that BCLA was unable to carry out field testing of the Ozone Detector Cards to the extent originally planned.

The SCAQMD Quality Assurance Manager (QAM) also conducted a TSA of the SCAQMD field activities. Battelle's Quality Manager prepared a TSA checklist, which was reviewed and approved by EPA's AMS Center Quality Manager and then provided to the SCAQMD QAM for use in the TSA. In the TSA, the SCAQMD QAM visited the monitoring sites in Upland and Rubidoux on September 1 and 3, 2010, respectively, and observed the use of the Ozone Detector Cards, operation of the FEM, and the recording of ozone and other data by SCAQMD field operators. The SCAQMD QAM reported his observations in writing to the Battelle QA Manager. No deviations from the test/QA plan were found as a result of the field TSA of SCAQMD activities.

TSA reports were prepared and copies were distributed to EPA.

4.2.3 Audit of Data Quality

Records generated in the verification test received a one-over-one review before these records were used to calculate, evaluate, or report verification results. Data were reviewed by a Battelle technical staff member involved in the verification test. The person performing the review added his/her initials and the date to a hard copy of the record being reviewed.

100% of the verification test data was reviewed for quality by the Verification Test Coordinator, and at least 10% of the data acquired during the verification test and 100% of the calibration and QC data were audited. Battelle’s Quality Manager, or designee, traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

Chapter 5
Statistical Methods

The statistical methods used to evaluate the quantitative performance factors listed in Section 3.3 are presented in this chapter. The semi-quantitative nature of the Ozone Detector Card readings determines the types of statistical comparisons that can be done to evaluate the performance parameters. The statistical comparisons are described in the following sections. Qualitative observations were also used to evaluate verification test data.

5.1 Accuracy

The accuracy of the Ozone Detector Cards with respect to the FEM was assessed as a percentage of readings in the correct Ozone Detector Cards indication range, i.e.:

$$\textit{Accuracy} = (\textit{Number in Range}/\textit{Number of Trials}) \times 100 \tag{1}$$

Where the *Number in Range* is the number of total Ozone Detector Card readings reported as being in the Ozone Detector Card indication range that encompasses the corresponding FEM ozone reading, and the *Number of Trials* is the total number of such comparisons for which FEM readings fell within that range. This calculation of accuracy was performed with the data from each of the challenge ozone concentrations in the laboratory testing, and with the data obtained by SCAQMD at field sites. Readings from Ozone Detector Cards exposed simultaneously, and readings from Ozone Detector Cards read in the laboratory by more than one user, were included in this calculation as separate trials (i.e., all Ozone Detector Card/FEM comparisons were treated as independent data for this calculation).

5.2 Variability of Readings

Variability of the Ozone Detector Card readings was evaluated using only the data from the repeated laboratory trials at five ozone challenge concentrations. For each of those concentrations, variability was determined as the number of Ozone Detector Card indication ranges into which the user readings fell. That is, at ozone concentration X (e.g.):

$$\textit{Variability X} = (\textit{\# of Ranges with Readings at Ozone Concentration X}) \tag{2}$$

The ideal result for variability is a value of 1 (i.e., all readings in a single Ozone Detector Card range). Note that the variability is independent of, and not an indication of, the accuracy of the card readings.

5.3 Duplication

Ozone Detector Card duplication was assessed in terms of the percentage of readings in which a single user reported a result in the same card indicator range from two reagent spots exposed simultaneously (regardless of whether that range agreed with FEM ozone results). Ozone Detector Card duplication was calculated as:

$$Duplication = (Number\ Same\ Range_d / Number\ Duplicates_d) \times 100 \qquad (3)$$

where the *Number Same Range*$_d$ is the number of cases in which a user reading simultaneously exposed reagent spots reported the same indication range from each spot. The *Number Duplicates*$_d$ is the total number of cases in which one user read such duplicate exposed reagent spots. Duplication was calculated both for those cases in which the duplicate spots were on the same card (intra-card duplication) and for those cases in which the duplicate spots were on different cards (inter-card duplication). These calculations were performed for the data from each of the ozone concentrations in laboratory testing, and separately for any cases of duplicate cards used in the field testing performed by SCAQMD and BCLA.

User agreement was calculated in the same manner, except using data from multiple users reading the same exposed reagent spot on an Ozone Detector Card, i.e.:

$$User\ Agreement = (Number\ Same\ Range_u / Number\ Duplicates_u) \times 100 \qquad (4)$$

Where the *Number Same Range*$_u$ is the number of cases in which two users reading the same exposed reagent spot reported the same Ozone Detector Card indication range, and the *Number Duplicates*$_u$ is the total number of cases in which two users read the same exposed reagent spot. This calculation was performed for the data from the duplicate users with each of the ozone concentrations in laboratory testing, and separately for any cases of duplicate users in the field testing performed by SCAQMD and BCLA.

5.4 Effect of Light Intensity

The effect of light intensity on Ozone Detector Card performance was assessed using the data from the laboratory testing (Section 3.2.2), by calculating the accuracy, variability, and duplication of readings (Sections 5.1 through 5.3) of the test data at each of the three light intensity conditions. Those results were compared to indicate whether light intensity has any apparent effect on the Ozone Detector Card performance at a constant ozone concentration. Accuracy or duplication results that differed by more than 20% accuracy or 20% duplication were taken as evidence of a significant light intensity effect. Similarly, variability results that differed by one or more Ozone Detector Card indication ranges were taken as evidence of a significant light intensity effect.

5.5 Effect of Ambient Conditions

To assess the impact of outdoor ambient conditions, the field data from the SCAQMD field testing were separated into those results for which the Ozone Detector Card reading agreed with that expected based on the FEM ozone reading, and those for which the card and FEM results did not agree. The temperature, RH, and wind speed data for the two sets of results were then compared to investigate whether there were significant differences in conditions that may have contributed to the differences in accuracy of the Ozone Detector Cards. Comparison of the data sets for significance of differences was based on *t*-test comparisons of means, using a 95% significance level of any differences. When data sets contained small numbers of samples ($n \leq 6$), an alternative procedure was also used in which the confidence interval of the mean of those data was estimated based on tabulated values of C_n and the equation:

$$\mu = \bar{x} \pm C_n R \quad (5)$$

where μ is the population mean, $\bar{x}$ is the mean of a small set of samples, and R is the range of the values.[5]

5.6 Operational Factors

Operational factors such as ease of use, readability of color ranges, etc., were evaluated based on observations recorded by Battelle and field staff. A laboratory notebook was maintained and data sheets were filled out by Ozone Detector Card users to record their observations. Cost was evaluated by reviewing price lists provided by the vendor for the Ozone Indicator Cards.

Chapter 6
Test Results

6.1 Laboratory Results

Tables 6-1 through 6-7 show the laboratory test results obtained at ozone concentrations of approximately 0, 30, 50, 70, 90, 130, and 150 to >200 ppbv, respectively. Each of these tables shows the Ozone Detector Card number and spot number, the FEM ozone concentration measured during the Ozone Detector Card exposure, the expected Ozone Detector Card range based on the FEM reading, and the range readings recorded by the two Battelle card readers. Table 6-8 shows the results obtained with blank spots (i.e., newly uncovered, not exposed to ozone) during the laboratory testing. Cases in which a reader's visual reading does not match the expected range are shaded gray in Tables 6-1 to 6-8.

Tables 6-1 through 6-7 illustrate that the Ozone Detector Card ranges reported by the two Battelle card readers often were lower than the expected range based on the corresponding FEM ozone reading, especially at the higher delivered ozone concentrations. At ozone concentrations of 90 ppbv and above (Tables 6-5 to 6-7), the great majority of user range readings were lower than the expected range. Tables 6-1 to 6-8 also show that in most cases the readings recorded by the two card readers (who were non-technical Battelle staff members) were the same. The readings recorded by these staff from reagent spots exposed to zero ozone concentrations in the test chamber (Table 6-1) always matched the expected reading of 1. The readings recorded by these staff from reagent spots not exposed at all before the visual reading was made (Table 6-8) matched the expected reading of 1 in all but two of 72 total readings.

Table 6-1. Laboratory Ozone Detector Card Data – 0 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
21	1	0.5	1	1	1
21	5	0.5	1	1	1
22	1	0.5	1	1	1
22	5	0.5	1	1	1
23	1	0.5	1	1	1
23	5	0.5	1	1	1
24	1	0.5	1	1	1
24	5	0.5	1	1	1
25	3	0.6	1	1	1
25	5	0.6	1	1	1
26	3	0.6	1	1	1
26	5	0.6	1	1	1
27	3	0.6	1	1	1
27	5	0.6	1	1	1
28	3	0.6	1	1	1
28	5	0.6	1	1	1

a**:** Based on FEM ozone concentration reading; range 1 = nominally 10 to 45 ppbv.

Table 6-2. Laboratory Ozone Detector Card Data – 30 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
25	1	28.1	1	1	1
25	2	28.1	1	1	1
26	1	28.1	1	1	1
26	2	28.1	1	1	1
27	1	28.1	1	1	1
27	2	28.1	1	1	1
28	1	28.1	1	1	1
28	2	28.1	1	1	1
17	2	32.7	1	1	1
17	3	32.7	1	1	1
18	2	32.7	1	2	1
18	3	32.7	1	2	1
19	2	32.7	1	2	1
19	3	32.7	1	2	1
20	2	32.7	1	1	1
20	3	32.7	1	1	1

a**:** Based on FEM ozone reading; range 1 = nominally 10 to 45 ppbv. User readings that do not match the expected range are shown in shaded cells.

Table 6-3. Laboratory Ozone Detector Card Data – 50 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
13	1	49.3	2	2	1
13	3	49.3	2	2	1
14	1	49.3	2	2	2
14	3	49.3	2	2	2
15	1	49.3	2	2	2
15	3	49.3	2	2	3
16	1	49.3	2	2	2
16	3	49.3	2	2	2
9	3	52.8	2	2	2
9	5	52.8	2	2	2
10	3	52.8	2	2	2
10	5	52.8	2	2	3
11	3	52.8	2	1	1
11	5	52.8	2	1	1
12	3	52.8	2	1	1
12	5	52.8	2	1	1

a**:** Based on FEM ozone reading; range 2 = nominally 45 to 75 ppbv. User readings that do not match the expected range are shown in shaded cells.

Table 6-4. Laboratory Ozone Detector Card Data – 70 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
17	1	63.8	2	2	1
17	4	63.8	2	2	1
18	1	63.8	2	2	1
18	4	63.8	2	2	1
19	1	63.8	2	2	2
19	4	63.8	2	2	2
20	1	63.8	2	2	2
20	4	63.8	2	2	1
29	2	68.6	2	2	2
29	4	68.6	2	2	2
30	2	68.6	2	2	1
30	4	68.6	2	2	1
31	2	68.6	2	2	1
31	4	68.6	2	2	1
32	2	68.6	2	2	1
32	4	68.6	2	2	1

a**:** Based on FEM ozone reading; range 2 = nominally 45 to 75 ppbv. User readings that do not match the expected range are shown in shaded cells.

Table 6-5. Laboratory Ozone Detector Card Data – 90 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
9	1	93.9	3	2	2
9	2	93.9	3	2	2
10	1	93.9	3	2	2
10	2	93.9	3	2	2
11	1	93.9	3	2	3
11	2	93.9	3	2	3
12	1	93.9	3	2	3
12	2	93.9	3	2	2
21	2	89.9	3	2	2
21	4	89.9	3	2	2
22	2	89.9	3	2	3
22	4	89.9	3	2	3
23	2	89.9	3	2	2
23	4	89.9	3	2	2
24	2	89.9	3	2	2
24	4	89.9	3	2	2
33	1	89.8	3	2	2
33	5	89.8	3	2	2
34	1	89.8	3	2	2
34	5	89.8	3	2	2
35	1	89.8	3	2	2
35	5	89.8	3	2	2
36	1	89.8	3	2	2
36	5	89.8	3	2	2
37	2	90.2	3	2	2
37	3	90.2	3	2	2
38	2	90.2	3	2	1
38	3	90.2	3	2	2
39	2	90.2	3	2	2
39	3	90.2	3	2	2
40	2	90.2	3	2	2
40	3	90.2	3	2	2

a**:** Based on FEM ozone reading; range 3 = nominally 75 to 105 ppbv. User readings that do not match the expected range are shown in shaded cells.

Table 6-6. Laboratory Ozone Detector Card Data – 130 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
29	3	132.3	4	2	2
29	5	132.3	4	2	2
30	3	132.3	4	2	3
30	5	132.3	4	2	3
31	3	132.3	4	2	2
31	5	132.3	4	2	2
32	3	132.3	4	2	2
32	5	132.3	4	2	2
13	4	121.6	4	2	2
13	5	121.6	4	2	2
14	4	121.6	4	2	2
14	5	121.6	4	2	2
15	4	121.6	4	2	2
15	5	121.6	4	2	3
16	4	121.6	4	2	3
16	5	121.6	4	2	3
33	3	131.5	4	2	2
33	4	131.5	4	2	2
34	3	131.5	4	2	2
34	4	131.5	4	2	2
35	3	131.5	4	2	2
35	4	131.5	4	2	3
36	3	131.5	4	2	3
36	4	131.5	4	2	3
37	4	132.0	4	2	2
37	5	132.0	4	2	3
38	4	132.0	4	2	2
38	5	132.0	4	2	3
39	4	132.0	4	2	2
39	5	132.0	4	2	2
40	4	132.0	4	2	2
40	5	132.0	4	2	3

a**:** Based on FEM ozone reading; range 4 = nominally > 105 ppbv. User readings that do not match the expected range are shown in shaded cells.

Table 6-7. Laboratory Ozone Detector Card Data – 150 to >200 ppbv.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
41	2	155.2	4	2	3
41	5	155.2	4	2	2
42	2	155.2	4	2	2
42	5	155.2	4	2	3
43	2	155.2	4	2	3
43	5	155.2	4	2	3
44	2	155.2	4	2	2
44	5	155.2	4	2	2
41	1	160.9	4	2	2
41	3	160.9	4	2	4
42	1	160.9	4	2	3
42	3	160.9	4	2	4
43	1	160.9	4	2	3
43	3	160.9	4	2	4
44	1	160.9	4	2	2
44	3	160.9	4	2	4
45	1	196.3	4	2	3
45	2	196.3	4	2	3
46	1	196.3	4	2	3
46	2	196.3	4	2	3
47	1	196.3	4	2	3
47	2	196.3	4	2	2
48	1	196.3	4	2	2
48	2	196.3	4	2	3
45	4	199.6	4	2	2
45	5	>200[b]	4	2	3
46	4	>200	4	2	2
46	5	>200	4	2	2
47	4	>200	4	2	2
47	5	>200	4	2	3
48	4	>200	4	2	2
48	5	>200	4	2	2

a**:** Based on FEM ozone reading; range 4 = nominally > 105 ppbv. User readings that do not match the expected range are shown in shaded cells.
b: Exceeded 200 ppbv upper range limit of FEM.

Table 6-8. Laboratory Ozone Detector Card Data – Blank Spots.

Card Number	Spot Number	Expected Range[a]	User 1 Range Reading	User 2 Range Reading
13	2	1	1	1
14	2	1	1	1
15	2	1	1	1
16	2	1	1	1
25	4	1	1	1
26	4	1	1	1
27	4	1	1	1
28	4	1	1	1
29	1	1	1	1
30	1	1	1	1
31	1	1	1	1
32	1	1	1	1
9	4	1	1	1
10	4	1	1	1
11	4	1	1	1
12	4	1	1	1
17	5	1	1	1
18	5	1	1	2
19	5	1	1	1
20	5	1	1	1
21	3	1	1	1
22	3	1	1	1
23	3	1	1	1
24	3	1	1	1
33	2	1	1	1
34	2	1	1	1
35	2	1	1	1
36	2	1	1	1
37	1	1	1	1
38	1	1	1	1
39	1	1	1	1
40	1	1	1	1
41	4	1	1	1
42	4	1	1	1
43	4	1	1	1
44	4	1	1	3

a: Based on absence of ozone exposure; range 1 = nominally 10 to 45 ppbv. User readings that do not match the expected range are shown in shaded cells.

6.1.1 Accuracy

The accuracy of the Ozone Detector Cards with respect to the FEM was assessed as a percentage of readings in the correct Ozone Detector Card indication range as described in Section 5.1. Table 6-9 summarizes the accuracy found at each of the ozone concentrations used in the laboratory.

Table 6-9. Accuracy Results at Laboratory Ozone Concentrations.

FEM Ozone Concentration, ppbv (Expected Range)	# of Card Readings in Range	# of Trials	Accuracy
Blank (1)	70	72	97%
0 (1)	32	32	100%
30 (1)	28	32	88%
50 (2)	20	32	63%
70 (2)	21	32	66%
90 (3)	5	64	7.8%
130 (4)	0	64	0%
150 to >200 (4)	4	64	6.3%

Table 6-9 shows that the accuracy of the Ozone Detector Cards was 100% or nearly so for unexposed blanks (97%) and for cards exposed in the test chamber to 0 ppbv ozone (100%). Accuracy decreased slightly for cards exposed to low levels of ozone (88% at 30 ppbv), and was markedly lower when cards were exposed to moderate levels of ozone (63% at 50 ppbv and 66% at 70 ppbv). At higher ozone concentrations, the accuracy of the Ozone Detector Cards was very low with less than 8% accuracy at 90 ppbv and an aggregate accuracy of 3.1% (4 out of 128 readings) for ozone concentrations of 130 ppbv and greater. Overall accuracy thus was 95.6% when a range reading of 1 was expected, 64.1% when a range reading of 2 was expected, 7.8% when a range reading of 3 was expected, and 3.1% when a range reading of 4 was expected. Accuracy results in Table 6-9 for ozone concentrations near range boundaries (i.e., 50 and 70 ppbv) fall between those for concentrations near range midpoints (i.e., 30 and 90 ppbv). However, Table 6-9 indicates that ozone concentration rather than position within range is the dominant factor affecting Ozone Detector Card accuracy.

The great majority of the discrepancy between the FEM ozone concentrations and the user Ozone Detector Card readings were due to user readings that were lower than expected based on the FEM readings. Of the 212 total card readings that did not agree with the expected range based on the FEM reading, 1 user reading was two ranges high, 7 user readings were one range high, 104 user readings were one range low, and 100 user readings were two ranges low.

6.1.2 Variability of Readings

The variability of the Ozone Detector Card readings was evaluated as described in Section 5.2. Table 6-10 shows the variability of the user readings of the Ozone Detector Cards at each of the ozone concentrations evaluated. Cases in which a user's visual reading does not match the expected range are shaded gray in Table 6-10.

Table 6-10. Summary of Variability of Ozone Detector Card Readings for Individual Ozone Concentrations.

FEM Ozone Concentration ppbv (Expected Range)	# of Card Readings in Range 1	# of Card Readings in Range 2	# of Card Readings in Range 3	# of Card Readings in Range 4	Variability (# of ranges)
Blank (1)	70	1	1	0	3
0 (1)	32	0	0	0	1
30 (1)	28	4	0	0	2
50 (2)	10	20	2	0	3
70 (2)	11	21	0	0	2
90 (3)	1	58	5	0	3
130 (4)	0	53	11	0	2
150 to >200 (4)	0	46	14	4	3

Table 6-10 shows that blank reagent spots were classified in three ranges. It is possible that the one blank reading classified as Range 3 was the result of a data recording error by the reader, as the blanks showed little discoloration when viewed by the test operator. Ozone Detector Cards exposed to 0 ppbv of ozone were always classified as Range 1 for a variability of 1. Ozone Detector Cards exposed to 30, 70, or 130 ppbv of ozone showed a variability of 2, and Ozone Detector Cards exposed to 50, 90, or 150 to >200 ppbv of ozone showed a variability of 3. Overall variability thus was 3, whether a range reading of 1, 2, 3, or 4 was expected. Table 6-10 shows that the overall variability at ozone concentrations near range boundaries (i.e., 50 and 70 ppbv) was essentially the same as the variability at concentrations near range midpoints (i.e., 30 and 90 ppbv). However, the fraction of readings outside the central range is greater at 50 or 70 ppbv (i.e., 11 or 12 out of 32 readings) than at 90 ppbv (i.e., 6 out of 64 readings).

6.1.3 Duplication

Ozone Detector Card duplication was assessed as described in Section 5.3. Intra-card duplication was determined by comparing readings from the same user for two spots on the same Ozone Detector Card which had been exposed to the same ozone concentration at the same time. Table 6-11 presents results for intra-card duplication in the laboratory testing. In that testing, two spots from each of four Ozone Detector Cards were exposed simultaneously and then read by two readers. A minimum of two replicates of each test were performed so there were a minimum of 16 readings of duplicate spots from the same card (8 from each reader). Table 6-11 shows that intra-card duplication ranged from 75% at 50 ppbv and 150 to >200 ppbv ozone, to 100% with 0 ppbv ozone. Intra-card duplication was 94% at 70 and 90 ppbv ozone. Overall intra-card duplication thus was 93.8% when a range reading of 1 was expected, 84.4% when a range reading of 2 was expected, 93.8% when a range reading of 3 was expected, and 76.6% when a range reading of 4 was expected. Table 6-11 shows that intra-card variability at ozone concentrations near range boundaries (i.e., 50 and 70 ppbv) was not markedly different from the variability at concentrations near range midpoints (i.e., 30 and 90 ppbv).

Table 6-11. Summary of Intra-Card Duplication for Laboratory Ozone Concentrations.

FEM Ozone Concentration (ppbv)	# of Duplicate Spot Readings in Agreement	Total # of Duplicate Spot Readings	Intra-Card Duplication
0	16	16	100%
30	14	16	88%
50	12	16	75%
70	15	16	94%
90	30	32	94%
130	27	32	84%
150 to >200	22	32	75%

Inter-card duplication was assessed by comparing readings from a single card user for reagent spots on different Ozone Detector Cards exposed at the same time. Each set of four cards results in 24 individual comparisons per reader for this analysis. With two readers and two replicates the total number of comparisons is at least 96. Table 6-12 presents the results for inter-card duplication. Table 6-12 shows that inter-card duplication ranged from 48% at 50 ppbv ozone, to 100% with 0 ppbv ozone. Inter-card duplication was 71% to 85% at other ozone concentrations. Overall inter-card duplication thus was 91.7% when a range reading of 1 was expected, 59.4% when a range reading of 2 was expected, 85.4% when a range reading of 3 was expected, and 47.4% when a range reading of 4 was expected. Table 6-12 shows that inter-card variability at ozone concentrations near range boundaries (i.e., 50 and 70 ppbv) was lower than the variability at either of the concentrations near range midpoints (i.e., 30 and 90 ppbv).

Table 6-12 shows that except for the 0 ppbv data, at all ozone concentrations the inter-card duplication was lower than the corresponding intra-card duplication (Table 6-11). The greatest differences occurred at 50 and 70 ppbv ozone. This comparison indicates that reagent spots exposed simultaneously on the same cards provide greater consistency of readings than do reagent spots exposed simultaneously on different cards.

Table 6-12. Summary of Inter-Card Duplication for Laboratory Ozone Concentrations.

FEM Ozone Concentration (ppbv)	# of Duplicate Spot Readings in Agreement	Total # of Duplicate Spot Readings	Inter-Card Duplication
0	96	96	100%
30	80	96	83%
50	46	96	48%
70	68	96	71%
90	164	192	85%
130	140	192	73%
150 to >200	142	192	74%

User agreement in the laboratory testing was also assessed as described in Section 5.3. Table 6-13 presents the results for user agreement at each ozone concentration tested, based on comparison of readings by multiple users of the same exposed reagent spots. As in the calculation of intra-card duplication, there were a minimum of 16 readings of the same spots by the two readers. Table 6-13 shows that user agreement ranged from 31% at 70 ppbv ozone, to 100% with 0 ppbv ozone. User agreement was 44% to 81% at other ozone concentrations, and 94% with blank (unexposed) reagent spots. Overall user agreement thus was 91.2% when a range reading of 1 was expected, 53.1% when a range reading of 2 was expected, 81.3% when a range reading of 3 was expected, and 54.7% when a range reading of 4 was expected. The lowest user agreement (31%) was seen at the 70 ppbv concentration, which is near the upper boundary of range 2 of the Ozone Detector Cards.

Table 6-13. Summary of User Agreement for Laboratory Ozone Concentrations.

FEM Ozone Concentration (ppbv)	# of Spots with Readings in Agreement	Total # of Spots read by Multiple Users	User Agreement
Blank	34	36	94%
0	16	16	100%
30	12	16	75%
50	12	16	75%
70	5	16	31%
90	26	32	81%
130	21	32	66%
150 to >200	14	32	44%

It might be expected that the duplication of readings would be reduced with ozone concentrations near the boundary of an Ozone Detector Card range, and this expectation is borne out to some extent by the results for 50 and 70 ppbv ozone in Tables 6-11 to 6-13. However, the results at these two concentrations are often not consistent, so any such boundary effect does not strongly determine the test results.

Table 6-13 shows varying agreement between the two Battelle staff members who read the Ozone Detector Cards in the laboratory testing. User agreement was high for reagent spots unexposed to ozone, but ranged from 31% agreement to 81% agreement with exposed reagent spots. The disagreement between the two card readers was not due to random variation in their readings. The readings of User 1 showed less variation than did those of User 2. When the two disagreed on the reading of a reagent spot, the readings of User 1 were generally higher than those of User 2 at ozone concentrations up to 70 ppbv, and were generally lower than those of User 2 at ozone concentrations of 90 ppbv and greater. These differences were not due to any color-blindness, visual impairment, or use of sunglasses by the card readers, as these factors were avoided in selecting the staff members to read the cards, consistent with the test/QA plan.[3]

6.1.4 Effect of Light Intensity

The data from the testing of light intensity effects during laboratory ozone exposures are listed in Table 6-14, which shows the Ozone Detector Card identification (lettered A through H), the reagent spot number, the lighting conditions, the expected Ozone Detector Card range based on the delivered ozone concentrations of 97 to 100 ppbv, and the visual readings of Ozone Detector Card range provided by the two Battelle card readers. Visual readings that did not match the expected Ozone Detector Card range are shaded in Table 6-14. The results of the light intensity testing are summarized in Table 6-15. Based on the criteria indicated in Section 5.4, Table 6-15 shows no significant effect of light intensity on the accuracy, variability, or user agreement of the Ozone Detector Cards. On the other hand, both intra- and inter-card duplication showed differences greater than the 20% criterion, with the lowest duplication in both cases occurring at the brightest illumination condition. The results for the effect of light intensity on duplication of readings are not entirely internally consistent, as a substantial difference between the laboratory and dark conditions was seen for intra-card duplication, but not for inter-card duplication. Note that the ozone concentration of approximately 100 ppbv was near the upper limit of range 3 (i.e., nominally 75 to 105 ppbv), and this may have contributed to variability in the users' range readings.

6.2 SCAQMD Field Results

This section reports the results of the field testing conducted by SCAQMD in the fall season of 2010. Additional data and results from initial field testing conducted by SCAQMD in the fall of 2009 are shown in Appendix A. As noted in Section 3.4, a new batch of Ozone Detector Cards was used for the fall 2010 field period.

Field testing in the fall of 2010 took place at SCAQMD's Crestline, Upland, and Rubidoux monitoring sites. The elevation difference among these sites was noted in Section 3.2.2. Note that solar UV intensity increases by approximately 5% per 1,000 m increase in elevation,[6] so the maximum difference in site elevations would lead to approximately 6% higher solar UV radiation at the Crestline site than at the lowest sites. Based on the results in Section 6.1.4, this difference is clearly insignificant in terms of the performance of the cards.

Table 6-14. Data from Laboratory Testing of Effect of Light Intensity on Ozone Indicator Card Readings.

Card	Spot Number	Lighting Conditions	Expected Range[a]	User 1 Reading	User 2 Reading
A	4	Dark	3	3	3
A	5	Dark	3	3	4
B	4	Dark	3	3	3
B	5	Dark	3	3	4
C	4	Dark	3	3	3
C	5	Dark	3	3	4
D	4	Dark	3	3	3
D	5	Dark	3	3	4
A	1	Laboratory	3	3	2
A	2	Laboratory	3	3	2
B	1	Laboratory	3	3	3
B	2	Laboratory	3	3	4
C	1	Laboratory	3	3	2
C	2	Laboratory	3	3	3
D	1	Laboratory	3	3	3
D	2	Laboratory	3	3	3
E	2	Bright	3	3	3
E	5	Bright	3	3	4
F	2	Bright	3	3	3
F	5	Bright	3	3	4
G	2	Bright	3	3	3
G	5	Bright	3	4	4
H	2	Bright	3	2	3
H	5	Bright	3	3	4

a: Based on approximately 100 ppbv ozone test concentration; range 3 = nominally 75 to 105 ppbv.

Table 6-15. Laboratory Results for Light Intensity Testing on Ozone Detector Cards.

Lighting Condition	Accuracy	Variability (# of ranges)	Intra-Card Duplication	Inter-Card Duplication	User Agreement
Dark	75%	2	50%	75%	50%
Laboratory	75%	3	75%	65%	50%
Bright	63%	3	25%	52%	50%

All card exposures were made during daylight hours, and almost entirely between 10:00 am and 5:00 pm, consistent with normal schedules for the testing personnel. Average ozone levels during the card exposure periods ranged from approximately 28 to 126 ppbv. Ambient conditions during the testing varied widely, e.g., the average air temperature during card exposures ranged from 44 to 107 °F. Table 6-16 shows the Ozone Detector Card number and spot number, the average FEM ozone concentration measured during the Ozone Detector Card exposure, the expected Ozone Detector Card range based on the average FEM reading, the Ozone Detector Card range reported by the SCAQMD user of each card, and the ambient temperature, RH, and wind speed during the exposure. Cards and reagent spots that were exposed simultaneously can be identified in Table 6-16 by the identical values for FEM ozone, temperature, RH, and wind speed. Cases in which the user's visual reading does not match the expected range are shaded in Table 6-16.

In the fall season field period in 2010, SCAQMD staff also read every Ozone Detector Card reagent spot immediately after the protective foil covering was removed from the spot. All of the 249 such readings were recorded by the users as indicating a range of 1. This result contrasts with the blank spot readings obtained by SCAQMD in the fall season of 2009 (see Appendix A, Section A1.1) which showed readings of 2 before any ozone exposure on the 17 reagent spots checked. This difference is likely due to the use of a new set of Ozone Detector Cards in the fall season 2010 testing, and indicates that color development can occur in the reagent spots after extended storage as suggested in Appendix A.

6.2.1 Accuracy

Table 6-16 lists 246 cases in which the expected Ozone Detector Card reading can be compared to the user's reading (in three other cases the user recorded an initial reading when the foil was first removed from a reagent spot, but then did not record a final reading after the ozone exposure). Of those 246 cases, the user's reading agreed with the expected reading in 172 cases, resulting in an overall accuracy of 69.9%.

The accuracy is further broken down in Table 6-17, which shows the number of cases, number of cases with agreement, and resulting accuracy for each category of the expected Ozone Detector Card range (i.e., 1, 2, 3, or 4). Table 6-16 shows that the Ozone Detector Card accuracy was nearly 100% when the reading expected based on FEM data was a 2, but that accuracy fell off at both lower and higher expected readings. When a reading of 3 was expected, accuracy of about 70% was achieved. However, when a reading of 1 was expected, the Ozone Detector Card readings frequently overestimated the ozone level, resulting in accuracy of 16.7%. Most importantly, the Ozone Detector Cards showed accuracy of only 10% in indicating ozone levels in the highest range of 4 (nominally above

105 ppbv). This result is similar to that observed in the laboratory testing (see Table 6-9) indicating low accuracy for the Ozone Detector Cards when challenged with relatively high ozone concentrations.

Table 6-16. Data from 2010 Field Testing by SCAQMD.[a]

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[b]	User Range Reading	Temperature (°F)	RH (%)	Wind Speed (mph)
1	1	89.0	3	2	100.8	15.8	7.4
1	2	89.0	3	2	100.8	15.8	7.4
1	3	91.8	3	2	106.5	13.2	8.3
1	4	91.8	3	2	106.5	13.2	8.3
2	1	101.2	3	3	105.8	20.2	8.7
2	2	101.2	3	3	105.8	20.2	8.7
2	3	95.9	3	3	103.2	22.9	0.4
2	4	95.9	3	3	103.2	22.9	0.4
3	1	91.2	3	3	103.8	22.4	9.6
3	2	91.2	3	3	103.8	22.4	9.6
3	3	89.8	3	3	102.2	24.0	10.7
3	4	89.8	3	3	102.2	24.0	10.7
4	1	82.4	3	2	91.2	25.2	4.9
4	2	82.4	3	2	91.2	25.2	4.9
4	3	81.6	3	2	89.0	29.8	7.2
4	4	81.6	3	2	89.0	29.8	7.2
5	1	83.7	3	3	98.6	19.0	9.4
5	2	83.7	3	3	98.6	19.0	9.4
5	3	89.1	3	3	97.0	24.1	13.0
5	4	89.1	3	3	97.0	24.1	13.0
6	1	98.5	3	3	104.1	10.2	8.3
6	2	98.5	3	3	104.1	10.2	8.3
6	3	83.8	3	3	102.7	17.2	5.5
6	4	83.8	3	3	102.7	17.2	5.5
7	1	89.4	3	3	103.3	17.9	5.4
7	2	89.4	3	3	103.3	17.9	5.4
7	3	93.7	3	3	100.1	20.6	6.0
7	4	93.7	3	3	100.1	20.6	6.0
8	1	55.2	2	2	74.8	56.6	5.9
8	2	55.2	2	2	74.8	56.6	5.9
8	3	53.7	2	2	75.9	54.7	6.5
8	4	53.7	2	2	75.9	54.7	6.5
9	1	51.8	2	2	70.3	57.6	6.2
9	2	51.8	2	2	70.3	57.6	6.2
9	3	48.4	2	2	70.7	56.9	8.1
9	4	48.4	2	2	70.7	56.9	8.1
10	1	64.8	2	2	77.3	39.7	5.8
10	2	64.8	2	2	77.3	39.7	5.8
10	3	60.5	2	2	77.6	41.0	7.8
10	4	60.5	2	2	77.6	41.0	7.8
11	1	77.9	3	2	86.2	30.3	7.3
11	2	77.9	3	2	86.2	30.3	7.3
11	3	76.0	3	2	85.6	34.3	8.6
11	4	76.0	3	2	85.6	34.3	8.6

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[b]	User Range Reading	Temperature (°F)	RH (%)	Wind Speed (mph)
12	1	53.7	2	2	94.6	20.2	3.7
12	2	53.7	2	2	94.6	20.2	3.7
12	3	49.7	2	2	93.5	22.2	5.9
12	4	49.7	2	2	93.5	22.2	5.9
13	1	59.5	2	2	89.6	28.6	5.1
13	2	59.5	2	2	89.6	28.6	5.1
13	3	58.5	2	2	88.7	28.4	9.1
13	4	58.5	2	2	88.7	28.4	9.1
14	1	71.7	2	2	91.1	24.1	1.6
14	2	71.7	2	2	91.1	24.1	1.6
14	3	71.2	2	2	89.1	29.9	4.9
14	4	71.2	2	2	89.1	29.9	4.9
15	1	79.5	3	2	88.8	28.4	4.4
15	2	79.5	3	2	88.8	28.4	4.4
15	3	76.5	3	2	88.1	28.8	9.7
15	4	76.5	3	2	88.1	28.8	9.7
16	1	55.1	2	2	77.5	48.3	7.4
16	2	55.1	2	2	77.5	48.3	7.4
16	3	55.0	2	2	76.5	49.9	8.6
16	4	55.0	2	2	76.5	49.9	8.6
1	5	73.2	2	2	101.6	9.3	2.3
2	5	73.2	2	2	101.6	9.3	2.3
3	5	73.7	2	2	100.1	9.5	5.1
4	5	73.7	2	2	100.1	9.5	5.1
5	5	74.8	2	2	100.7	9.2	7.3
6	5	74.8	2	2	100.7	9.2	7.3
7	5	74.8	2	2	102.3	7.9	2.5
8	5	74.8	2	2	102.3	7.9	2.5
9	5	67.5	2	2	100.5	19.5	0.5
10	5	67.5	2	2	100.5	19.5	0.5
11	5	71.2	2	2	100.4	19.1	3.2
12	5	71.2	2	2	100.4	19.1	3.2
13	5	76.6	3	2	100.5	19.9	1.5
14	5	76.6	3	2	100.5	19.9	1.5
15	5	77.3	3	2	97.1	23.9	3.4
16	5	77.3	3	2	97.1	23.9	3.4
17	1	111.0	4	3	102.0	21.9	6.0
17	2	111.0	4	3	102.0	21.9	6.0
17	3	126.0	4	3	102.0	22.0	6.0
17	4	126.0	4	4	102.0	22.0	6.0
18	1	70.5	2	2	107.0	24.9	6.0
18	2	70.5	2	2	107.0	24.9	6.0
18	3	108.0	4	2	102.0	28.2	3.0
18	4	108.0	4	3	102.0	28.2	3.0
19	1	114.0	4	3	99.1	32.5	9.0
19	2	114.0	4	3	99.1	32.5	9.0
19	3	116.5	4	3	99.0	31.1	7.0
19	4	116.5	4	3	99.0	31.1	7.0
20	1	55.3	2	2	88.0	38.0	8.0
20	2	55.3	2	2	88.0	38.0	8.0

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[b]	User Range Reading	Temperature (°F)	RH (%)	Wind Speed (mph)
20	3	79.4	3	3	92.0	31.0	7.0
20	4	79.4	3	3	92.0	31.0	7.0
21	1	56.3	2	2	79.0	48.0	5.0
21	2	56.3	2	2	79.0	48.0	5.0
21	3	69.5	2	2	87.0	36.0	4.0
21	4	69.5	2	2	87.0	36.0	4.0
22	1	81.5	3	3	95.0	28.8	7.0
22	2	81.5	3	3	95.0	28.8	7.0
22	3	93.0	3	2	94.0	29.4	10.0
22	4	93.0	3	2	94.0	29.4	10.0
23	1	91.0	3	3	98.0	24.0	7.0
23	2	91.0	3	3	98.0	24.0	7.0
23	3	99.5	3	3	97.0	28.0	9.0
23	4	99.5	3	3	97.0	28.0	9.0
24	1	41.0	1	2	68.0	77.0	4.0
24	2	41.0	1	2	68.0	77.0	4.0
24	3	48.0	2	2	69.0	74.0	3.0
24	4	48.0	2	2	69.0	74.0	3.0
25	1	42.0	1	2	68.0	67.0	4.0
25	2	42.0	1	2	68.0	67.0	4.0
25	3	40.5	1	2	67.0	68.0	4.0
25	4	40.5	1	2	67.0	68.0	4.0
26	1	54.5	2	2	74.0	52.0	2.0
26	2	54.5	2	2	74.0	52.0	2.0
26	3	47.5	2	2	73.0	56.0	8.0
26	4	47.5	2	2	73.0	56.0	8.0
27	1	44.5	1	2	79.0	50.0	5.0
27	2	44.5	1	2	79.0	50.0	5.0
27	3	63.5	2	2	82.0	42.0	7.0
27	4	63.5	2	2	82.0	42.0	7.0
28	1	43.5	1	2	90.0	33.0	5.0
28	2	43.5	1	2	90.0	33.0	5.0
28	3	49.5	2	2	89.0	32.0	7.0
28	4	49.5	2	2	89.0	32.0	7.0
29	1	54.0	2	2	86.0	36.0	6.0
29	2	54.0	2	2	86.0	36.0	6.0
29	3	55.5	2	2	85.0	38.0	7.0
29	4	55.5	2	2	85.0	38.0	7.0
30	1	67.0	2	2	87.0	32.0	5.0
30	2	67.0	2	2	87.0	32.0	5.0
30	3	59.0	2	2	86.0	38.0	6.0
30	4	59.0	2	2	86.0	38.0	6.0
31	1	69.0	2	2	85.0	36.0	7.0
31	2	69.0	2	2	85.0	36.0	7.0
31	3	57.0	2	2	84.0	41.0	8.0
31	4	57.0	2	2	84.0	41.0	8.0
32	1	47.5	2	2	73.0	64.0	6.0
32	2	47.5	2	2	73.0	64.0	6.0
32	3	50.5	2	2	72.0	65.0	5.0
32	4	50.5	2	2	72.0	65.0	5.0

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[b]	User Range Reading	Temperature (°F)	RH (%)	Wind Speed (mph)
33	1	36.0	1	2	66.0	71.0	4.0
33	2	36.0	1	2	66.0	71.0	4.0
33	3	38.0	1	2	66.0	71.0	4.0
33	4	38.0	1	2	66.0	71.0	4.0
17	5	65.0	2	2	84.0	39.0	6.0
18	5	65.0	2	2	84.0	39.0	6.0
19	5	75.0	3	3	85.0	37.0	7.0
20	5	75.0	3	3	85.0	37.0	7.0
21	5	78.0	3	2	98.0	18.0	5.0
22	5	78.0	3	2	98.0	18.0	5.0
23	5	71.0	2	2	99.0	17.0	4.0
24	5	71.0	2	2	99.0	17.0	4.0
25	5	60.5	2	2	97.0	28.0	6.0
26	5	60.5	2	2	97.0	28.0	6.0
27	5	68.0	2	2	95.5	30.5	7.0
28	5	68.0	2	2	95.5	30.5	7.0
29	5	51.0	2	2	93.0	39.5	6.0
30	5	51.0	2	2	93.0	39.5	6.0
31	5	63.5	2	2	93.0	37.0	5.0
32	5	63.5	2	2	93.0	37.0	5.0
34	1	101.6	3	3	90.9	19.0	9.6
34	2	101.6	3	3	90.9	19.0	9.6
34	3	89.4	3	3	89.5	20.3	8.8
34	4	89.4	3	3	89.5	20.3	8.8
35	1	69.7	2	2	87.0	29.2	4.5
35	2	69.7	2	2	87.0	29.2	4.5
35	3	70.7	2	2	86.1	32.1	3.4
35	4	70.7	2	2	86.1	32.1	3.4
36	1	80.9	3	3	88.3	30.5	3.3
36	2	80.9	3	3	88.3	30.5	3.3
36	3	80.6	3	3	87.8	34.8	3.7
36	4	80.6	3	3	87.8	34.8	3.7
37	1	75.7	3	3	86.5	32.8	2.6
37	2	75.7	3	3	86.5	32.8	2.6
37	3	97.3	3	3	87.3	31.0	6.8
37	4	97.3	3	3	87.3	31.0	6.8
38	1	81.7	3	3	86.5	32.5	8.7
38	2	81.7	3	3	86.5	32.5	8.7
38	3	77.4	3	3	86.0	33.7	10.2
38	4	77.4	3	3	86.0	33.7	10.2
39	1	70.5	2	3	72.1	37.3	8.1
39	2	70.5	2	3	72.1	37.3	8.1
39	3	76.6	3	3	73.2	37.1	5.6
39	4	76.6	3	3	73.2	37.1	5.6
40	1	72.3	2	2	76.6	27.2	2.6
40	2	72.3	2	2	76.6	27.2	2.6
40	3	75.2	3	3	77.8	25.9	2.7
40	4	75.2	3	3	77.8	25.9	2.7
41	1	86.1	3	3	81.0	23.4	3.3
41	2	86.1	3	3	81.0	23.4	3.3

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[b]	User Range Reading	Temperature (°F)	RH (%)	Wind Speed (mph)
41	3	82.2	3	3	81.2	19.1	4.6
41	4	82.2	3	3	81.2	19.1	4.6
42	1	82.4	3	3	86.8	9.2	3.8
42	2	82.4	3	2	86.8	9.2	3.8
42	3	82.7	3	2	87.1	8.5	5.1
42	4	82.7	3	2	87.1	8.5	5.1
43	1	81.1	3	2	87.4	11.4	6.5
43	2	81.1	3	2	87.4	11.4	6.5
43	3	89.6	3	3	87.2	12.1	7.6
43	4	89.6	3	3	87.2	12.1	7.6
44	1	63.6	2	2	73.4	45.2	7.0
44	2	63.6	2	2	73.4	45.2	7.0
44	3	65.9	2	2	73.6	41.4	7.8
44	4	65.9	2	2	73.6	41.4	7.8
45	1	40.2	1	2	52.0	86.0	6.2
45	2	40.2	1	2	52.0	86.0	6.2
45	3	42.2	1	2	52.7	87.5	8.5
45	4	42.2	1	2	52.7	87.5	8.5
46	1	75.6	3	2	68.9	39.8	6.8
46	2	75.6	3	2	68.9	39.8	6.8
46	3	77.5	3	2	69.9	37.2	4.6
46	4	77.5	3	2	69.9	37.2	4.6
47	1	31.7	1	2	69.7	45.0	3.4
47	2	31.7	1	2	69.7	45.0	3.4
47	3	32.0	1	2	70.3	43.2	4.0
47	4	32.0	1	2	70.3	43.2	4.0
48	1	34.2	1	2	72.2	36.6	7.8
48	2	34.2	1	2	72.2	36.6	7.8
48	3	34.4	1	2	72.8	34.5	12.4
48	4	34.4	1	2	72.8	34.5	12.4
49	1	27.7	1	1	63.3	48.1	4.5
49	2	27.7	1	1	63.3	48.1	4.5
49	3	28.9	1	1	64.0	48.0	3.7
49	4	28.9	1	1	64.0	48.0	3.7
50	1	31.0	1	1	68.7	31.8	3.6
50	2	31.0	1	1	68.7	31.8	3.6
50	3	36.6	1	2	69.0	34.5	8.8
50	4	36.6	1	2	69.0	34.5	8.8
34	5	83.6	3	3	80.2	30.8	6.5
35	5	83.6	3	3	80.2	30.8	6.5
36	5	81.0	3	3	78.4	31.7	4.1
37	5	81.0	3	3	78.4	31.7	4.1
38	5	53.0	2	2	73.5	50.4	4.8
39	5	53.0	2	2	73.5	50.4	4.8
40	5	50.8	2	2	72.2	51.5	6.3
41	5	50.8	2	2	72.2	51.5	6.3
42	5	51.5	2	2	69.9	47.2	1.7
43	5	51.5	2	2	69.9	47.2	1.7
44	5	51.8	2	2	73.8	41.2	3.8
45	5	51.8	2	2	73.8	41.2	3.8

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[b]	User Range Reading	Temperature (°F)	RH (%)	Wind Speed (mph)
46	5	39.9	1	2	44.7	99.5	10.5
47	5	39.9	1	2	44.7	99.5	10.5
48	5	35.4	1	--	44.4	99.5	8.1
49	5	35.4	1	--	44.4	99.5	8.1
50	5	35.4	1	--	44.4	99.5	8.1

a: Data in this table are original measurements reported to the number of digits representative of each monitor's accuracy, so an inconsistent number of significant figures are presented.

b: Based on FEM ozone concentration reading.

Table 6-17. Ozone Detector Card Accuracy in Fall Season 2010 SCAQMD Testing by Expected Card Reading Category

Expected Ozone Detector Card Reading[a]	Number of Cases[b]	Number of Cases with Agreement of User and Expected Readings[b]	Accuracy (%)
1	36	6	16.7
2	106	104	98.1
3	94	61	64.9
4	10	1	10.0
Total all ranges	246	172	69.9

a: Expected range based on simultaneous average FEM reading.
b: From data in Table 6-16.

6.2.2 Duplication

Most of the fall season 2010 SCAQMD field data in Table 6-16 were obtained by exposing two reagent spots on a single Ozone Detector Card simultaneously. Those tests always used reagent spots numbered 1 and 2, or 3 and 4, and provide data to assess intra-card duplication. Some data were also obtained by exposing a single reagent spot on each of two different Ozone Detector Cards simultaneously. Those tests always used reagent spots numbered 5, and provide data to assess inter-card duplication. No data were collected in which the exposed reagent spots were read by more than one user, so the fall 2010 SCAQMD data do not provide any information on user agreement.

A total of 100 intra-card comparisons are shown in Table 6-16, and of that total three comparisons show disagreement between user readings for two reagent spots on the same card exposed simultaneously. Consequently, intra-card duplication was 97% in the fall season 2010 SCAQMD testing. Of those three cases of disagreement, one (card number 42, spots 1 and 2) occurred when the user recorded readings of 2 and 3 for the two spots when a reading of 3 would have been expected based on the FEM reading. The other two cases (card 17, spots 3 and 4, and card 18, spots 3 and 4) both occurred when a reading of 4 would have been expected based on the FEM reading. Those four spots produced readings of 2 and 3, and 3 and 4, respectively, illustrating that the Ozone Detector Cards did not consistently give a reading of 4 when ambient ozone levels should have produced such a reading. Overall, intra-card duplication was 100% when a range reading of 1 or 2 was expected, 97.3% when a range reading of 3 was expected, and 60% (3 agreements in 5 cases) when a range reading of 4 was expected.

Table 6-16 lists 23 cases in which the reagent spots numbered 5 on two different Ozone Detector Cards were exposed simultaneously and visual readings were recorded. Of those 23 cases (consisting of 1 case, 16 cases, and 6 cases with the expected range reading of 1, 2, and 3, respectively), there were none in which different readings were obtained from the two reagent spots. Thus inter-card duplication was 100% in the fall 2010 SCAQMD testing.

6.2.3 Effect of Ambient Conditions

In assessing the effect of ambient conditions on the accuracy of Ozone Detector Card readings in the SCAQMD field testing, it must be recognized that Ozone Detector Card accuracy varies with the ozone level present (see Tables 6-9 and 6-17) and that ambient ozone levels are clearly dependent on the ambient meteorological conditions. For example, the observed FEM ozone readings in the fall season 2010 testing were significantly positively correlated with ambient temperature ($r^2 = 0.53$, by linear regression). Consequently, the effect of ambient conditions is first evaluated using the entire data set, and then similarly evaluated by categorizing the data by expected Ozone Detector Card reading based on the FEM readings.

Considering the fall season 2010 SCAQMD data set as a whole, a comparison is shown in Table 6-18 of the average meteorological conditions for the 172 cases of accurate Ozone Detector Card readings, and for the 74 cases of inaccurate Ozone Detector Card readings.

Table 6-18. Comparison of Meteorological Conditions with Accurate and Inaccurate Ozone Detector Card Readings in Fall Season 2010 SCAQMD Field Testing

Card Accuracy	Number of Cases	Temperature (°F)[a]	Relative Humidity (%)[a]	Wind Speed[a]
Accurate	172	86.6 (± 11.1)	33.1 (± 13.9)	5.8 (± 2.4)
Inaccurate	74	81.5 (± 15.9)	39.6 (± 23.0)	6.2 (± 2.4)
Significant Difference[b]		Y	Y	N

a: Mean (± standard deviation) shown.
b: Based on *t*-test.

Table 6-18 shows that on average the ambient temperature was significantly higher, and the ambient RH significantly lower, during the exposure periods that resulted in accurate Ozone Detector Card readings relative to those periods that resulted in inaccurate readings. However, the variability of both temperature and RH was substantially greater in the dataset of inaccurate results than in the dataset of accurate results. The ranges of conditions overlap greatly, and it is not clear that ambient conditions strongly determined the accuracy of Ozone Detector Card readings. There was no significant difference in ambient wind speed between the two sets of results. These comparisons are explored further in Table 6-19, which breaks out the comparisons of Table 6-18 according to the category of the expected Ozone Detector Card range (i.e., 1, 2, 3, or 4) based on the simultaneous FEM reading.

Table 6-19. Comparison of Meteorological Conditions with Accurate and Inaccurate Ozone Detector Card Readings by Expected Ozone Card Reading

Expected Card Reading	Card Accuracy	Number of Cases	Temperature (°F)[a]	Relative Humidity (%)[a]	Wind Speed (mph)[a]
1	Accurate	6[b]	65.3 (± 2.6)	42.6 (± 8.4)	3.9 (± 0.4)
	Inaccurate	30	67.2 (± 10.8)	60.3 (± 21.7)	6.1 (± 2.8)
Significant Difference[c]			N	Y	Y
2	Accurate	104	84.7 (± 10.4)	37.3 (± 15.0)	5.5 (± 2.0)
	Inaccurate	2[d]	72.1 (0)	37.3 (0)	8.1 (0)
Significant Difference[e]			N	N	N
3	Accurate	61	91.6 (± 9.1)	25.1 (± 7.3)	6.7 (± 2.8)
	Inaccurate	33	89.8 (± 9.8)	24.1 (± 9.4)	6.2 (± 2.3)
Significant Difference			N	N	N
4	Accurate	1	102.0	22.0	6.0
	Inaccurate	9	100.7 (± 1.6)	27.7 (± 4.6)	6.2 (± 2.2)
Significant Difference[e]			N	N	N

a: Mean (± standard deviation) shown.
b: Confidence intervals (95%) based on treatment of ranges of data with Equation 5 are 65.3 (± 2.2) °F, 42.6 (± 6.5) %RH, and 3.9 (± 0.36) mph. Significant difference also found for temperature when range of data is used.
c: Significant differences based on *t*-test, unless otherwise indicated.
d: Two readings taken simultaneously, therefore meteorological data are identical.
e: Differences judged significant if single value from minority result differs from mean of majority results by more than two standard deviations of majority results.

The breakdown in Table 6-19 is limited by the small number of data points in some categories, but does not show any consistent effects from the ambient conditions across the reading categories. Significant effects from RH and wind speed are found for readings with an expected level of 1, but those effects are not seen in the other categories. Overall, the results in Tables 6-18 and 6-19 do not indicate that Ozone Detector Card readings are affected by the ambient temperature, RH, or wind speed over the range of conditions encountered.

6.3 BCLA Field Results

Table 6-20 summarizes the Ozone Detector Card results obtained by BCLA volunteers in field testing in the winter and spring seasons of 2009-2010. In this test period, BCLA volunteers used the Ozone Detector Cards at elementary and middle schools, and at offices, and in both outdoor and indoor air.

Table 6-20. BCLA Field Results, 12/18/09 to 5/13/10

Card Number	Spot Number	User 1 Reading	User 2 Reading
BC-19	1	2	--
BC-19	2	2	--
BC-68	1	3	--
BC-68	2	3	--
BC-68	4	4	--
BC-69	1	4	--
BC-69	2	3	--
BC-69	3	2	--
BC-69	4	3	--
BC-69	5	3	--
BC-70	1	3	--
BC-70	2	3	--
BC-53	1	4	--
BC-12	1	4	--
BC-14	1	2	--
BC-14	2	2	--
BC-14	3	2	--
BC-14	4	2	--
BC-19	3	3	--
BC-53	2	4	--
BC-33	1	3	--
BC-33	2	2	--
BC-33	3	2	--
BC-33	4	3	--
BC-33	5	4	--
BC-32	1	4	--
BC-32	2	4	--
BC-32	3	3	--
BC-32	4	2	--
BC-32	5	4	--
BC-19	4	3	--
BC-12	2	3	--
BC-19	5	2	--
BC-53	3	4	--
BC-12	3	3	--
BC-53	4	4	--
BC-11	1	3	--
BC-11	2	--	3
BC-11	3	3	--

Card Number	Spot Number	User 1 Reading	User 2 Reading
BC-11	4	--	3
BC-11	5	3	--
BC-12	4	4	--
BC-53	5	3	--
BC-12	5	4	--
BC-52	1	4	--
BC-52	2	4	--
BC-52	3	3	--
BC-52	4	3	--
BC-52	5	3	--
BC-66	1	2	2
BC-66	2	3	3
BC-66	3	3	3
BC-66	4	2	2
BC-66	5	3	3
BC-67	1	2	2
BC-67	2	3	3
BC-67	3	3	3
BC-67	4	3	3
BC-67	5	4	4
BC-54	1	3	--
BC-54	2	3	--
BC-54	3	2	--
BC-54	4	2	--
BC-54	5	3	--

6.3.1 Duplication

The 2009-2010 BCLA field data summarized in Table 6-20 include no cases in which multiple reagent spots on the same Ozone Detector Card were exposed simultaneously. As a result, no assessment of intra-card duplication could be made with those data. Similarly, no cases could be identified in which reagent spots on different Ozone Detector Cards were exposed simultaneously and in the same location. Consequently, no assessment of inter-card duplication could be made. However, Table 6-21 shows 10 cases in which the same exposed reagent spot was read by two different users. In all 10 of those cases the readings from the two users were in agreement, resulting in user duplication of 100%.

6.4 Operational Factors

During the laboratory portion of the testing, the following observations were made on the operational factors of the Ozone Detector Cards.

The two Battelle staff members who served as card readers reported having a difficult time matching the color change in the reagent spot following exposure to the colors on the reference color wheel printed on the Ozone Detector Cards. Common observations were that the hue of the reference color wheel did not match the actual color change in the reagent spot. The color change of the spot was described as more yellow in color than the reference color wheel (at low ozone concentrations), or more red than the reference color wheel (at high ozone concentrations). Additionally, both readers remarked that the color change was often "in between" the colors of the reference color wheel. Ozone ranges 1, 2, and 3 are each represented on the reference color wheel with a single color while ozone range 4 is represented by a color gradient. Users often described the color change in a reagent spot as being (e.g.) darker than the 1 range, but not as dark as the 2 range.

The two Battelle staff members who served as card readers rarely read reagent spots on the Ozone Detector Cards as being in the 4 range (indicating > 105 ppbv ozone) even when the ozone concentration in the exposure chamber was elevated to 200 ppbv or more. These high concentration tests were the source of many comments from the two readers about the color of the spot not matching the color of the reference color wheel. The infrequent reporting of a range of 4, even when the delivered ozone concentrations greatly exceeded the nominal threshold for that range, is noteworthy.

As noted in Section 3.2.1, the presence of the Ozone Detector Cards in the test chamber during laboratory testing markedly reduced the ozone concentration in the delivered air stream. This effect persisted as long as the cards remained in the test chamber, and was the same whether reagent spots on the cards were covered or uncovered. This observation suggests that the cardboard material of the cards themselves absorbed or reacted with ozone. This characteristic of the Ozone Detector Cards could potentially introduce bias in the measurement of ambient ozone, especially under conditions of still air. No investigation was done in this verification of what range of wind speeds would be needed to minimize this ozone removal effect. As noted in Section 3.2.1, air speeds through the test chamber in the laboratory testing were low, i.e., approximately 1 cm/s (0.6 m/min (2 ft/min)).

Prior to use, all the Ozone Detector Cards were stored as received from the manufacturer, i.e., in individual plastic sleeves inside a cardboard box. The light intensity testing was the final laboratory test procedure, and was conducted with cards which had been stored for approximately three months after receipt at Battelle. This time period is one-quarter of the nominal 1 year shelf life of the cards stated by the vendor, however the length of storage before the cards were shipped to Battelle is unknown. With a few of those cards it was observed that reagent spots already exhibited a slight color change when the foil covering was first removed (i.e., with no exposure to ozone), though no problem with the foil covering was apparent. Reagent spots that had been nearest the open end of the card's plastic sleeve during storage were more likely to be discolored upon removal of the foil than reagent spots located farther away from the sleeve opening. This observation suggests that protection of the reagent spots during storage in individual plastic sleeves is not absolute. A similar observation was made by SCAQMD in initial field testing of the Ozone Detector Cards (see Appendix A). This observation indicates that users should occasionally check the color of unexposed reagent spots during use of the Ozone Detector Cards.

During the field portions of the testing by SCAQMD and BCLA, the following observations were made on the operational factors of the Ozone Detector Cards.

SCAQMD field operators noted difficulty in comparing the color change on the reagent spots to the reference color wheel on the Ozone Detector Cards. Initially, during the fall season 2009 field period SCAQMD users reacted to this difficulty by reporting readings that were halfway between ranges on the Ozone Detector Cards (e.g., a reading of 2.5; see discussion in Appendix A). In the fall season 2010 field period, users noted that reagent spots exposed outdoors at the SCAQMD sites could appear to give different readings when read under different lighting conditions. For example, at the Upland site on September 1, 2010, the user recorded on the data sheet: "Spots 1 and 2 borderline 2 in sunlight, 3 in shade." The SCAQMD QAM also noted examples of this issue in conducting the TSA of SCAQMD activities, and took photographs under differing conditions to illustrate the differing appearance of reagent spots. The instructions printed on each Ozone Detector Card do not call for standardization of lighting conditions when reading the reagent spot color. While those instructions implicitly assume that the appearance of the reference color wheel and an exposed reagent spot will change in the same way with the ambient lighting conditions, the user comments suggest that that is not the case. It may be that the material or surface finish of the printed color wheel cause it to absorb or reflect the ambient light differently from an exposed reagent spot, causing a relative shift in the apparent color of the spot depending on ambient conditions.

BCLA field operators noted two operational factors consistent with comments in other parts of this verification. It was noted that the color change on reagent spots was hard to read, and the visual reading could fall into either of two adjacent ranges on the card. It was also noted that in one case a reagent spot already showed color development when its foil covering was first removed.

After reviewing the draft of this report the vendor of the Ozone Detector Cards provided comments on operational features of the cards. Those comments are summarized below.

Regarding user comments that the hue of the reagent spot did not match the color of the reagent spot, the vendor noted that the exact hue of the exposed reagent spot will vary due to the presence in air of trace reactive species other than ozone. The vendor suggested that printing a white ring between the inner rim of the color indicator wheel and the reagent spot would spatially separate the two, and might reduce the effect of differences in hue on the visual reading of ozone range.

Regarding user comments that visual readings fell between two adjacent ranges on the reference color wheel, the vendor noted that this will be the case for most readings. The vendor stated that the Ozone Detector Card is a tool for estimating the ozone level, and not a measuring instrument. According to the vendor, using a continuous scale of graduated color would not be desirable as it would suggest an accuracy for the card's readings that is not real.

The vendor commented that the absorption of ozone by the material that the cards are made of is not surprising, as ozone is known to be destroyed by reaction with many substances.

However, the vendor indicated that coating the cards with a more inert substance such as Teflon® is not possible. A potential solution might be to provide a Teflon mask to enclose the card, with a hole held over the exposed spot during exposures.
Regarding color development in reagent spots during long-term storage prior to use, the vendor indicated that gradual oxidation of the reagent spots by atmospheric oxygen causes this color production. Although ozone is destroyed by contact with the cardboard material of the card, oxygen is not, and may penetrate the cardboard to cause the color development. The vendor suggested that airtight storage of the cards might minimize this effect. Alternatively, sealing individual cards in oxygen-impermeable wrappings might minimize this oxidation.

Regarding the effect of different lighting conditions on the visual reading of exposed reagent spots, the vendor suggested that instructions could be added to the cards requiring that visual readings always be made in indirect sunlight (i.e., in shade). To assure consistency of indoor and outdoor readings, "indirect sunlight" might mean in shade outdoors and near a window indoors.

Finally, regarding the cost of the Ozone Indicator Cards, the vendor's standard price list shows a cost per card of approximately $1.60 per card when purchased in packages of 100, with lower prices per card for larger quantities. Individual cards can also be purchased from the vendor at a cost of approximately $3.00 per card.

Chapter 7
Performance Summary

Table 7-1 summarizes the performance observed from the Ozone Detector Cards in the laboratory and field testing. Shown in Table 7-1 are the results for each performance parameter determined in the laboratory testing, and in the field testing performed by SCAQMD and by BCLA. When ozone levels are known and sufficient Ozone Detector Card data are available, performance results are broken down by ozone level, in terms of the expected Ozone Detector Card range (1, 2, 3, or 4) that corresponds to the ozone level.

Table 7-1 shows that in both laboratory and field testing the Ozone Detector Cards exhibited lower accuracy and duplication of readings at ozone concentrations corresponding to the highest range reading of the cards (i.e., range 4). In laboratory testing the accuracy, variability, and duplication of the Ozone Detector Cards were sometimes worse when exposed to an ozone concentration near the boundary of a detection range than when exposed to a concentration near the middle of a range, but this effect was not consistently observed. The Ozone Detector Cards are relatively inexpensive (approximately $1.60 or less per card, when purchased in lots of 100 or more). Users reported the cards were easy to use, but users had difficulty in matching the color developed in the reagent spots with the color index printed on the cards. This difficulty may have contributed to the observed variability of card readings (e.g., in laboratory testing the reported card readings fell into three different card ranges regardless of the expected range reading). Bright simulated sunlight during laboratory ozone exposure, and temperature, RH, and wind speed during field use had little effect on Ozone Detector Card accuracy, but users reported that the lighting conditions under which exposed reagent spots were read could affect their reported readings.

Additional performance information obtained in initial SCAQMD field testing is included in Appendix A.

Table 7-1. Performance Summary for Ozone Indicator Cards

Performance Parameter	Testing Effort		
	Laboratory	SCAQMD Field	BCLA Field
Accuracy (%)[a]	Range[b] 1: 95.6 2: 64.1 3: 7.8 4: 3.1	Range 1: 16.7 2: 98.1 3: 64.9 4: 10.0	NA[c]
Variability (number of card ranges reported (4 ranges is maximum variability))[a]	Range 1: 3 2: 3 3: 3 4: 3	NA	NA
Intra-Card Duplication (%)[a]	Range 1: 93.8 2: 84.4 3: 93.8 4: 76.6	Range 1: 100 2: 100 3: 97.3 4: 60.0	NA
Inter-Card Duplication (%)[a]	Range 1: 91.7 2: 59.4 3: 85.4 4: 47.4	100[d]	NA
User Agreement (%)[a]	Range 1: 91.2 2: 53.1 3: 81.3 4: 54.7	NA	100[e]
Effect of Light Intensity on Color Development during Ozone Exposure	No effect on accuracy, variability, or user agreement; reduced intra-and inter-card duplication with Bright light condition	NA	NA
Effect of Ambient Conditions on Accuracy	NA	Full data set suggests higher accuracy with higher temperature and lower RH; breakdown by expected range shows no conclusive effects.	NA
Operational Factors	Easy to use; Difficult to match reagent spot color to color wheel; Presence of cards reduces ozone in test chamber; Development of color in reagent spots during storage of cards	Easy to use; Difficult to match reagent spot color to color wheel; Visual reading depends on ambient lighting conditions; Develop-ment of color in reagent spots during storage of cards	Easy to use; Difficult to match reagent spot color to color wheel; Development of color in one reagent spot during storage of cards

a: Performance shown for expected ranges of card readings, when information is available.
b: Range 1 = 10 to 45 ppbv; Range 2 = 45 to 75 ppbv; Range 3 = 75 to 105 ppbv; Range 4 = >105 ppbv.
c: NA = not applicable as no data on this parameter were collected from this effort.
d: Based on 23 total cases (insufficient data for breakdown by expected range).
e: Based on 10 total cases.

Chapter 8
References

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Appendix A

Results from Initial Field Tests of Ozone Detector Cards by SCAQMD October and November, 2009

A1.1 Field Data

Table A1-1 shows the ozone card indications and associated data obtained at SCAQMD field sites in initial field tests in the fall of 2009. These data were collected prior to final EPA approval of the test/QA plan, so they are considered to be supplemental data to the verification test. These initial tests were conducted between October 1 and November 2, 2009, at SCAQMD's Crestline, Riverside, and Santa Clarita monitoring sites. All card exposures were made during daylight hours, and almost entirely between 10:00 am and 5:00 pm, consistent with normal schedules for the testing personnel. Ambient ozone levels were always below 65 ppbv, and usually below 50 ppbv. Table A1-1 shows the Ozone Detector Card number and spot number, the average FEM ozone concentration measured during the Ozone Detector Card exposure, the expected Ozone Detector Card range based on the FEM reading, the Ozone Detector Card ranges reported by the SCAQMD user(s) of each card, and the ambient temperature, RH, and wind speed during the exposure. Because of the limited range of ambient ozone levels, the expected Ozone Detector Card ranges based on the FEM readings were always either 1 or 2. Cards and reagent spots that were exposed simultaneously can be identified in Table A1-1 by the identical values for FEM ozone, temperature, RH, and wind speed. Cases in which the user's visual reading does not match the expected range are shaded gray in Table A1-1. In several cases, one SCAQMD user recorded range indications as 2.5 when he found it difficult to choose between ranges 2 and 3. Those readings are shown as differing from the expected range only when the difference is greater than 1 full range (i.e., any difference of 0.5 range is not considered significant).

Table A1-1shows that the large majority of the Ozone Detector Card ranges reported by SCAQMD personnel in these initial tests were higher than the expected range based on the corresponding FEM ozone reading. In some cases the user readings were two ranges higher than the expected range based on the FEM data (i.e., a reading of 3 when a reading of 1 was expected). This observation raised concern that the reagent spots may have undergone a color change during storage that artificially elevated the visual reading, i.e., that a color change may have already occurred before the reagent spots were exposed to ambient air. To explore this hypothesis, SCAQMD personnel were instructed to remove the foil from unused spots on the Ozone Indicator Cards, and to immediately record their visual readings of the color intensity before any exposure to ozone. A total of 17 such unexposed spots were read by SCAQMD staff on November 2, 2009, and the resulting readings are shown in Table A1-2. The results in Table A1-2 confirm that unexpected color development occurred in the Ozone Indicator Cards, as all 17 unexposed spots showed a range of 2 when read by SCAQMD testing personnel. As a result of the data in Table A1-2, subsequent SCAQMD field testing included checks of unexposed reagent spots to assess color with no exposure to ozone.

Table A1-1. SCAQMD Ozone Detector Card Data from Initial Field Testing.

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading	Temperature (°C)	RH (%)	Wind Speed (mph)
SC07	1	40.6	1	3	-	91.2	2	3.0
SC07	2	40.6	1	3	-	91.2	2	3.0
SC08	1	40.6	1	3	-	91.2	2	3.0
SC08	2	40.6	1	3	-	91.2	2	3.0
SC07	3	43.9	1	3	-	90.0	2	12.5
SC07	4	43.9	1	3	-	90.0	2	12.5
SC08	3	43.9	1	3	-	90.0	2	12.5
SC08	4	43.9	1	3	-	90.0	2	12.5
SC13	1	45.5	2	2	2	84.0	6	10.0
SC13	2	45.5	2	2	2	84.0	6	10.0
SC41	1	45.5	2	2	2	84.0	6	10.0
SC41	2	45.5	2	2	2	84.0	6	10.0
SC13	3	41.7	1	2	3	85.6	5	8.0
SC13	4	41.7	1	2	3	85.6	5	8.0
SC41	3	41.7	1	2	3	85.6	5	8.0
SC41	4	41.7	1	2	3	85.6	5	8.0
SC25	1	43.7	1	2	-	63.8	17	3.4
SC25	2	43.7	1	3	-	63.8	17	3.4
SC26	1	43.7	1	2	-	63.8	17	3.4
SC26	2	43.7	1	3	-	63.8	17	3.4
SC25	3	46.9	2	3	-	66.1	12	4.4
SC25	4	46.9	2	3	-	66.1	12	4.4
SC26	3	46.9	2	3	-	66.1	12	4.4
SC26	4	46.9	2	3	-	66.1	12	4.4
SC27	1	63.9	2	2	-	71.3	11	3.6
SC27	2	63.9	2	2	-	71.3	11	3.6
SC28	1	63.9	2	2	-	71.3	11	3.6
SC28	2	63.9	2	2	-	71.3	11	3.6
SC27	3	64.8	2	2	-	70.8	14	3.3
SC27	4	64.8	2	2	-	70.8	14	3.3
SC28	3	64.8	2	2	-	70.8	14	3.3
SC28	4	64.8	2	2	-	70.8	14	3.3
SC42	1	35.0	1	2	2	65.0	47	6.8
SC42	2	35.0	1	2	2	65.0	47	6.8
SC49	1	35.0	1	2	2	65.0	47	6.8
SC49	2	35.0	1	2	2	65.0	47	6.8
SC42	3	36.0	1	2	2	65.1	39	3.4
SC42	4	36.0	1	2	2	65.1	39	3.4
SC49	3	36.0	1	2	2	65.1	39	3.4
SC49	4	36.0	1	2	2	65.1	39	3.4
SC29	1	44.7	1	3	-	52.2	69	5.1
SC29	2	44.7	1	3	-	52.2	69	5.1
SC30	1	44.7	1	3	-	52.2	69	5.1
SC30	2	44.7	1	3	-	52.2	69	5.1
SC29	3	51.4	2	3	-	66.3	53	8.0
SC29	4	51.4	2	3	-	66.3	53	8.0
SC30	3	51.4	2	3	-	66.3	53	8.0
SC30	4	51.4	2	3	-	66.3	53	8.0
SC43	1	54.4	2	2	-	74.1	45	15.1
SC43	2	54.4	2	2	-	74.1	45	15.1
SC44	1	54.4	2	2	-	74.1	45	15.1
SC44	2	54.4	2	2	-	74.1	45	15.1
SC43	3	48.1	2	2	-	71.1	46	12.8
SC43	4	48.1	2	2	-	71.1	46	12.8
SC44	3	48.1	2	2	-	71.1	46	12.8

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading	Temperature (°C)	RH (%)	Wind Speed (mph)
SC44	4	48.1	2	2	-	71.1	46	12.8
SC16	1	32.5	1	2	-	68.1	65	11.5
SC16	2	32.5	1	2	-	68.1	65	11.5
SC50	1	32.5	1	2	-	68.1	65	11.5
SC50	2	32.5	1	2	-	68.1	65	11.5
SC16	3	36.7	1	2	-	67.0	66	12.9
SC16	4	36.7	1	2	-	67.0	66	12.9
SC50	3	36.7	1	2	-	67.0	66	12.9
SC50	4	36.7	1	2	-	67.0	66	12.9
SC06	1	55.1	2	3	-	78.2	43	3.9
SC06	2	55.1	2	3	-	78.2	43	3.9
SC05	1	55.1	2	3	-	78.2	43	3.9
SC05	2	55.1	2	3	-	78.2	43	3.9
SC06	3	54.9	2	3	-	77.7	42	7.0
SC06	4	54.9	2	3	-	77.7	42	7.0
SC05	3	54.9	2	3	-	77.7	42	7.0
SC05	4	54.9	2	3	-	77.7	42	7.0
SC31	1	2.0	1	2	-	41.1	75	0.3
SC31	2	2.0	1	2	-	41.1	75	0.3
SC32	1	2.0	1	2	-	41.1	75	0.3
SC32	2	2.0	1	2	-	41.1	75	0.3
SC31	3	8.0	1	2	-	51.8	53	1.1
SC31	4	8.0	1	2	-	51.8	53	1.1
SC32	3	8.0	1	2	-	51.8	53	1.1
SC32	4	8.0	1	2	-	51.8	53	1.1
SC03	1	41.0	1	2.5	-	97.3	17	5.0
SC03	2	41.0	1	2.5	-	97.3	17	5.0
SC04	1	41.0	1	2.5	-	97.3	17	5.0
SC04	2	41.0	1	2.5	-	97.3	17	5.0
SC03	3	40.4	1	2.5	-	98.2	15	7.1
SC03	4	40.4	1	2.5	-	98.2	15	7.1
SC04	3	40.4	1	2.5	-	98.2	15	7.1
SC04	4	40.4	1	2.5	-	98.2	15	7.1
SC23	1	45.0	2	3	-	97.7	13	13.5
SC23	2	45.0	2	3	-	97.7	13	13.5
SC24	1	45.0	2	3	-	97.7	13	13.5
SC24	2	45.0	2	3	-	97.7	13	13.5
SC23	3	44.8	1	3	-	97.8	12	10.0
SC23	4	44.8	1	3	-	97.8	12	10.0
SC24	3	44.8	1	3	-	97.8	12	10.0
SC24	4	44.8	1	3	-	97.8	12	10.0
SC11	1	36.0	1	2	-	67.0	68	8.6
SC11	2	36.0	1	2	-	67.0	68	8.6
SC46	1	36.0	1	2	-	67.0	68	8.6
SC46	2	36.0	1	2	-	67.0	68	8.6
SC11	3	37.8	1	2	-	67.2	64	10.6
SC11	4	37.8	1	2	-	67.2	64	10.6
SC46	3	37.8	1	2	-	67.2	64	10.6
SC46	4	37.8	1	2	-	67.2	64	10.6
SC18	1	41.2	1	3	-	75.4	41	4.5
SC18	2	41.2	1	3	-	75.4	41	4.5
SC19	1	41.2	1	3	-	75.4	41	4.5
SC19	2	41.2	1	3	-	75.4	41	4.5
SC18	3	39.2	1	3	-	75.0	44	5.7
SC18	4	39.2	1	3	-	75.0	44	5.7
SC19	3	39.2	1	3	-	75.0	44	5.7

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading	Temperature (°C)	RH (%)	Wind Speed (mph)
SC19	4	39.2	1	3	-	75.0	44	5.7
SC33	1	45.0	2	3	-	56.1	40	6.5
SC33	2	45.0	2	3	-	56.1	40	6.5
SC34	1	45.0	2	3	-	56.1	40	6.5
SC34	2	45.0	2	3	-	56.1	40	6.5
SC33	3	46.5	2	3	-	58.4	35	8.0
SC33	4	46.5	2	3	-	58.4	35	8.0
SC34	3	46.5	2	3	-	58.4	35	8.0
SC34	4	46.5	2	3	-	58.4	35	8.0
SC21	1	40.3	1	2.5	-	83.0	23	4.8
SC21	2	40.3	1	2.5	-	83.0	23	4.8
SC22	1	40.3	1	2.5	-	83.0	23	4.8
SC22	2	40.3	1	2.5	-	83.0	23	4.8
SC21	3	40.7	1	2.5	-	82.3	26	7.0
SC21	4	40.7	1	2.5	-	82.3	26	7.0
SC22	3	40.7	1	2.5	-	82.3	26	7.0
SC22	4	40.7	1	2.5	-	82.3	26	7.0
SC35	1	42.9	1	3	-	61.4	29	3.2
SC35	2	42.9	1	3	-	61.4	29	3.2
SC36	1	42.9	1	3	-	61.4	29	3.2
SC36	2	42.9	1	3	-	61.4	29	3.2
SC35	3	48.3	2	3	-	66.0	20	2.8
SC35	4	48.3	2	3	-	66.0	20	2.8
SC36	3	48.3	2	3	-	66.0	20	2.8
SC36	4	48.3	2	3	-	66.0	20	2.8
SC09	1	49.1	2	2	-	82.1	21	14.3
SC09	2	49.1	2	2	-	82.1	21	14.3
SC47	1	49.1	2	2	-	82.1	21	14.3
SC47	2	49.1	2	2	-	82.1	21	14.3
SC09	3	51.8	2	2	-	79.8	23	14.6
SC09	4	51.8	2	2	-	79.8	23	14.6
SC47	3	51.8	2	2	-	79.8	23	14.6
SC47	4	51.8	2	2	-	79.8	23	14.6
SC01	1	53.4	2	3	-	88.8	20	3.0
SC01	2	53.4	2	3	-	88.8	20	3.0
SC17	1	53.4	2	3	-	88.8	20	3.0
SC17	2	53.4	2	3	-	88.8	20	3.0
SC01	3	51.3	2	3	-	85.3	23	7.7
SC01	4	51.3	2	3	-	85.3	23	7.7
SC17	3	51.3	2	3	-	85.3	23	7.7
SC17	4	51.3	2	3	-	85.3	23	7.7
SC02	1	49.0	2	2.5	-	90.6	12	8.6
SC02	2	49.0	2	2.5	-	90.6	12	8.6
SC20	1	49.0	2	2.5	-	90.6	12	8.6
SC20	2	49.0	2	2.5	-	90.6	12	8.6
SC02	3	50.0	2	2.5	-	89.9	12	5.4
SC02	4	50.0	2	2.5	-	89.9	12	5.4
SC20	3	50.0	2	2.5	-	89.9	12	5.4
SC20	4	50.0	2	2.5	-	89.9	12	5.4
SC37	1	49.5	2	3	-	71.4	21	3.2
SC37	2	49.5	2	3	-	71.4	21	3.2
SC38	1	49.5	2	3	-	71.4	21	3.2
SC38	2	49.5	2	3	-	71.4	21	3.2
SC37	3	52.5	2	2	-	72.5	16	3.5
SC37	4	52.5	2	3	-	72.5	16	3.5
SC38	3	52.5	2	2	-	72.5	16	3.5

Card Number	Spot Number	FEM Ozone Concentration (ppbv)	Expected Range[a]	User 1 Range Reading	User 2 Range Reading	Temperature (°C)	RH (%)	Wind Speed (mph)
SC38	4	52.5	2	2	-	72.5	16	3.5
SC12	1	40.3	1	2	-	82.8	5	5.2
SC12	2	40.3	1	2	-	82.8	5	5.2
SC14	1	40.3	1	2	-	82.8	5	5.2
SC14	2	40.3	1	2	-	82.8	5	5.2
SC12	3	37.6	1	2	-	83.2	4	2.6
SC12	4	37.6	1	2	-	83.2	4	2.6
SC14	3	37.6	1	2	-	83.2	4	2.6
SC14	4	37.6	1	2	-	83.2	4	2.6
SC39	1	45.9	2	2	-	54.8	32	4.2
SC39	2	45.9	2	2	-	54.8	32	4.2
SC40	1	45.9	2	2	-	54.8	32	4.2
SC40	2	45.9	2	2	-	54.8	32	4.2
SC39	3	46.0	2	2	-	51.8	35	5.7
SC39	4	46.0	2	3	-	51.8	35	5.7
SC40	3	46.0	2	2	-	51.8	35	5.7
SC40	4	46.0	2	2	-	51.8	35	5.7
SC48	1	36.6	1	2	-	86.1	12	4.1
SC48	2	36.6	1	2	-	86.1	12	4.1
SC48	3	35.1	1	2	-	87.1	11	3.7
SC48	4	35.1	1	2	-	87.1	11	3.7
SC15	1	36.6	1	2	-	86.1	12	4.1
SC15	2	36.6	1	2	-	86.1	12	4.1
SC45	1	36.6	1	2	-	86.1	12	4.1
SC45	2	36.6	1	2	-	86.1	12	4.1
SC15	3	35.1	1	2	-	87.1	11	3.7
SC15	4	35.1	1	2	-	87.1	11	3.7
SC45	3	35.1	1	2	-	87.1	11	3.7
SC45	4	35.1	1	2	-	87.1	11	3.7

Table A1-2. SCAQMD Readings of Ozone Indicator Reagent Spots Immediately After Removing Protective Foil (No Exposure to Ozone)

Card Number	Spot Number	Expected Range[a]	User 1 Range Reading
SC09	5	1	2
SC11	5	1	2
SC12	5	1	2
SC13	5	1	2
SC14	5	1	2
SC15	5	1	2
SC16	5	1	2
SC41	5	1	2
SC42	5	1	2
SC43	5	1	2
SC44	5	1	2
SC45	5	1	2
SC46	5	1	2
SC47	5	1	2
SC48	5	1	2
SC49	5	1	2
SC50	5	1	2

a: Based on absence of ozone exposure. User readings that do not match the expected range are shown in shaded cells.

A1.2 Accuracy

Accuracy of the Ozone Detector Cards was 0% when the expected range reading was 1 (121 total reagent spots), and 54% when the expected range reading was 2 (92 total reagent spots). This inaccuracy was likely caused by the bias introduced by the blank reagent spot color development that is discussed in Section A1.1 and shown in Table A1-2.

A1.3 Duplication

Ozone Detector Card duplication was assessed as described in Section 5.3. Intra-card duplication was determined by comparing the readings made by a single user of two reagent spots on a single Ozone Detector Card which had been exposed to ambient air over the same time period. Table A1-1 includes 106 total cases in which a user read two reagent spots on the same card that had been exposed simultaneously (98 cases for User 1 and 8 cases for User 2). User 1 indicated different readings for the two reagent spots in 4 of the 106 total cases. Therefore the intra-card duplication rate was 96.2%.

Inter-card duplication was assessed by comparing readings from a single card user for reagent spots on different Ozone Detector Cards exposed at the same time. In almost all the initial SCAQMD field testing, two reagent spots on each of two cards (4 total reagent spots) were exposed simultaneously. In those cases, each set of four spots results in 4 individual comparisons for inter-card duplication. In total, Table A1-1 includes 192 such comparisons from User 1 and 16 such comparisons from User 2. Of those 208 total comparisons for inter-card duplication, there were 6 cases (all with User 1) in which different readings were obtained with reagent spots exposed simultaneously on different cards. Therefore the inter-card duplication rate was 97.1%.

User agreement in the initial SCAQMD field testing was also assessed as described in Section 5.3. Table A1-1 shows that there were 16 cases in which two users read the same reagent spots. In those 16 cases, the two users recorded the same reading in 12 cases. Therefore the user duplication in the initial SCAQMD field testing was 75%.

A1.4 Effect of Ambient Conditions

The effect of ambient conditions (temperature, RH, wind speed) on Ozone Detector Card readings could not be determined in the initial SCAQMD field testing. The apparent upward bias in observed card readings, as described in Section A1.1, prevented assessment of the effect of ambient conditions on the accuracy of the readings.

A1.5 Operational Factors

The SCAQMD field operators who used the Ozone Detector Cards in the initial field testing had comments similar to those reported in Section 6.3 of this report. Although the Ozone Detector Cards were easy to use, the field operators stated that the color of the reagent spots after exposure to ozone did not match well with the colors of the color wheel printed on the card. Operators noted the occurrence of spot colors that appeared to be in between the colors of ranges on the color wheel. This occurrence is illustrated by the fact that one user recorded readings of 2.5, rather than 2 or 3, in this initial testing (see Table A1.1).

The initial field testing demonstrated one potential problem with the Ozone Detector Cards that was noted in Section 6.4: the possible development of color in reagent spots prior to removal of the foil covering. Table A1-2 shows that reagent spots on several cards had developed substantial color before their foil covering was removed. Whether this indicates a lack of integrity in the foil covering, or a problem in the procedure of storing the cards in their individual plastic sleeves in their original box, is not known.